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ABSTRACT

One of twelve water treatment technology units, this student manual on hydraulics provides instructional materials fcr three competencies. (The twelve units are designed for a continuing educatien training course for public water supply operators.) The competencies focus on the following areas: head loss in pipes in series, function loss in distribution system piping, and converting pressure to feet of head. For each competency, student objectives, resources (information sheets and appendixed material), learning activities, and evaluation activities are provided. The appendices contain information sheets on hydraulics. Generally, an evaluation form with answer key is provided for each competency. (JH)

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Water Treatment Technology

HYDRAULICS

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December, 1978

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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HYDRAULICS

EVALUATOR'S COPY

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EVALUATOR'S INSTRUCTIONS

Name _____

Address _____

_____

Phone _____ _____

This is your Evaluator's Copy of the HYDRAULICS unit. It contains all of the materials received by the operators who will be working on the unit. It also contains *answer keys* and *directions* for the evaluation of each competency. For each Competency Sheet, there is a COMPETENCY, a list of RESOURCES, LEARNING ACTIVITIES, and EVALUATION ACTIVITIES.

Your student operators will call you when they are ready to be evaluated. An operator may complete the evaluations in *any* order. S/he may choose to complete one at a time, or several at one time. *It is up to you and each operator to set convenient schedules for the evaluations.* It is important that the operators learn the skills listed in each competency. It is <u>your</u> job to be sure the operators can perform the competencies.

If an operator does <u>not</u> complete an evaluation correctly, s/he may try again later after practicing the skills. It would be helpful for you to tell the operators just how they should improve their knowledge and skills in order to complete the evaluation successfully. Be sure to call if you have any questions.

This package contains:

- - - - - HYDRAULICS unit

- - - - - Evaluations Forms for each Competency

You will receive instructions as to where to send the completed evaluation forms. Please be sure that the operator's name and your name are on the forms, as well as the date on which the evaluation was performed.

INSTRUCTIONS FOR THE STUDENT OPERATOR

The HYDRAULICS unit contains three competencies. A "competency" is a skill that is necessary for good on-the-job performance. Each competency in this unit is necessary for you to perform on the job according to the West Virginia Department of Health. There is a Competency Sheet to help you understand each competency.

DIRECTIONS FOR COMPLETING THE UNIT:

1. Read each Competency Sheet carefully. Every Competency Sheet contains:

   COMPETENCY
   Objectives
   RESOURCES
   LEARNING ACTIVITIES
   EVALUATION ACTIVITY(IES)

2. After reading the whole Competency Sheet, you should understand what will be expected of you.

3. Do the LEARNING ACTIVITIES that you think will help you the most. This may include reading some of the RESOURCES which have been included with the unit.

4. If you need additional help, ask an operator in your plant for assistance, or call your evaluator; he's there to help you.

5. When you are ready to complete the EVALUATION ACTIVITY for one or more competencies--call your evaluator. The two of you will schedule the best time for your evaluation.

   a. If you complete the evaluation correctly, go on to the next competency.
   b. If you do <u>not</u> complete the evaluation correctly, your evaluator will tell you what your mistakes were. You must go back and practice your skills and read the RESOURCES again. Call your evaluator when you are ready to try again. *You must wait at least one week before being re-evaluated on a competency.*

6. When you complete all your evaluations correctly you will receive a Certificate of Accomplishment and 0.6 Continuing Education Units of Credit.

7. If you want to go on to another unit, contact your evaluator for the materials. The procedure will be similar for all units.

AN EXPLANATION OF CONTINUING EDUCATION UNITS

For student operators in the OPERATOR-IN-TRAINING category who will be taking the certification examination for Class I, this course is an opportunity to increase your knowledge and competence in the treatment of water for human consumption. Successful completion of the manuals will also, it is hoped, make passing the certification exam much easier. The Continuing Education Units which you will get by taking this course will not decrease the minimum one year operating experience requirement for a Class I certificate.

For student operators who now hold a Class I certificate, the completion of all twelve manuals in the course will reduce the currently required three years of total operating experience for Class II certification by approximately four months. Thus, if you complete the course, you will need only two years and eight months of total operating experience before you take the Class II exam.

Here is a listing of the Continuing Education Unit (CEU) value of each of the manuals.

Manual	CEU Value
General Plant Operation	1.4
Taste, Odor, and Color	0.6
Chemistry/Bacteriology	2.5
Chlorination	2.5
Fluoridation	0.6
Filtration	1.2
Hydraulics	0.6
Distribution Systems	1.2
Pumps	0.6
Wells	1.0
Cross Connections	0.4
Springs	0.4
Total	13.0

For comparison with other types of training previously available, the CEU conversions below are given.

Public Water Supply Operator's Short Course (given by State Department of Health Personnel)	4 CEUs
One Semester Hour of College Credit	1.5 CEUs
One Year of College Credits (30 semester hours)	45 CEUs

COMPETENCY: Determine the head loss for two pipes connected in a series.

Objective: Describe the meaning of the term "head loss".

Objective: Demonstrate the ability to determine head loss for two pipes connected in series.

RESOURCES:

(a) Waterworks Manual - basic, Coordinating Council for Occupational Education, State of Washington, 1972 (P 49-77), pp 53, 67-68. -Blue Appendix-

(b) Resource Sheet, PIPE CAPACITY

(c) Table,"Friction Loss of Water Per 100 Feet Length of Pipe (Inside Diameter)", page 20, -Blue Appendix-

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find information about determining head loss.

(b) Using the Resource Sheet,including the Table, solve the problems given for determining head loss. Practice using the table by determining head loss for various lengths of pipe connected in series.

EVALUATION ACTIVITY: You will be expected to determine the head loss for two pipes connected in series. You may use the Resource Sheet and the Table as references during the evaluation.

PIPE CAPACITY*

The quantity of water a pipe can carry depends upon:

- the size and type of pipe
- the age and condition of pipe
- the head available.

The Table gives head loss for various sizes of pipe and rates of flow. To use the Table: find the appropriate gallons per minute on the right hand column. Then locate the loss in feet for the appropriate size pipe. For example: The loss in feet for 100 feet of 6" pipe and a rate of flow of 100 gpm is .17. The loss in feet for 14" pipe and a rate of flow of 750 gpm is .11.

The mathematical formula for determining pipe size is difficult to use. Therefore, the Table can be used to save time. The Table is based on a C-factor of 100. It will apply to pipes with considerable interior roughness. (The C-factor is an experimentally determined measure of the roughness of the interior of pipes).

Problem: A 6-inch diameter pipe is 3,000 feet long and is to carry 450 gallons per minute (gpm). What head loss will result?

Solution: The formula for determining head loss is:

$$\text{Head Loss} = \frac{\text{feet of pipe}}{100} \times \text{loss in feet per 100 ft. of pipe (see Table)}$$

therefore:

$$\text{Head Loss} = \frac{3{,}000}{100} \times 2.74$$

$$= 82.2 \text{ feet}$$

The same formula should be used in determining the head loss for two pipes connected in a series. See Figure 1, next page.

The quantity of water passing through both pipes is the same, but the head losses are quite different. Use the Table and assume both pipes have C-factors of 100. Find the head loss for each pipe.

(Continued)

* Adapted from Waterworks Manual-Basic, Coordinating Council for Occupational Education, State of Washington, 1972, pp. 64-68.

Use this formula:

$$\text{Head Loss} = \frac{\text{feet of pipe}}{100} \times \text{loss in feet per 100' of pipe}$$

for 8" pipe: $\frac{1000}{100} \times 0.15 = 1.5$ feet

for 4" pipe: $\frac{1000}{100} \times 4.4 = 44$ feet

If you add the head loss from each pipe 44 + 1.5, you find the total head loss of 45.5 for the two pipes connected in series.

The 2,000 ft-long pipe system from A to C can deliver 200 gpm from A to C with a head loss of 45.5 feet. Any other pipe (or pipes) that would deliver 200 gpm from A to C with the same 45.5 feet of head loss could be substituted for the 4-inch and 8-inch pipe and would be considered "equivalent" pipe. You could use 7,339 feet of 6-inch pipe or 256 feet of 3-inch pipe as equivalents to the 2,000 feet of 8-inch and 4-inch pipe in the original problem.

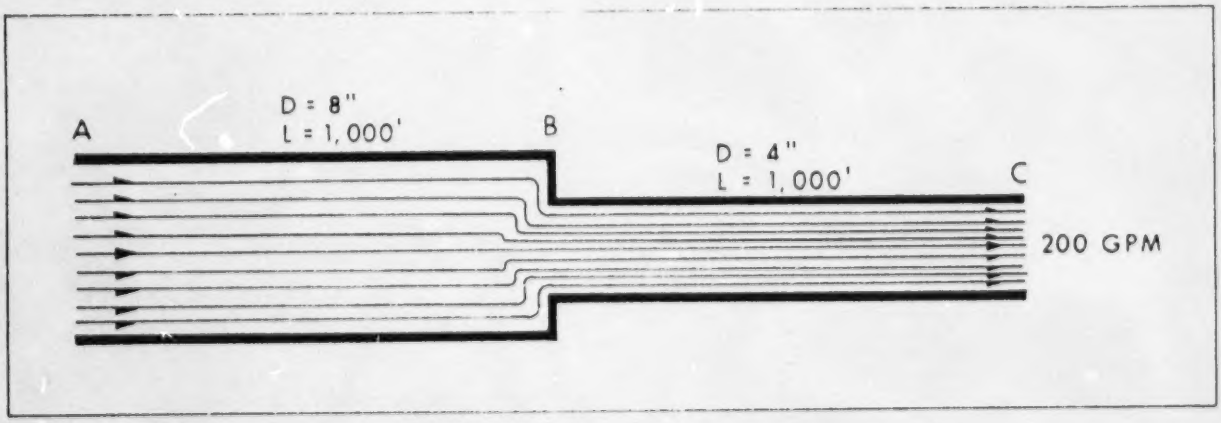


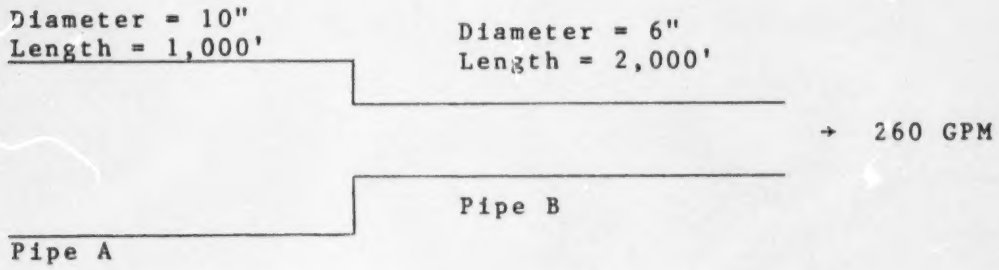
Fig. 1 Pipes in Series

Operator _____

Evaluator _____

Date _____

Determine the total head loss in feet for the two pipes connected in series as pictured below. Assume that the C-factor is 100.



$$\text{Head Loss} = \frac{\text{length of pipe in feet}}{100} \times \text{head loss in feet per 100' of pipe (see Table)}$$

* * * * * * * *

a. Head Loss in Pipe A = $\frac{1,000}{100}$ X .08 = 0.8 feet

b. Head Loss in Pipe B = $\frac{2,000}{100}$ X 1.0 = 20 feet

Total Head Loss = Head Loss in Pipe A plus Head Loss in Pipe B.

Total Head Loss = 20.8

COMPETENCY: Using the chart provided, determine the friction loss of water in three different sections of line in the distribution system.

Objective: Describe how friction loss might affect consumer service.

Objective: Describe the cause of friction loss.

RESOURCES:

(a) Chart, "Friction Loss of Water Per 100 Feet Length of Pipe", *page 20, -Blue Appendix-*

(b) Waterworks Manual - basic, Coordinating Council for Occupational Education, State of Washington, 1972, pp. 49-61, 64-70. *-Blue Appendix-*

(c) "Head Loss" Resource Sheet

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find information about determining head loss.

(b) Using the Resource Chart, practice determining friction loss for various sizes of pipe.

For example. You have a 6-inch pipe in your distribution system which delivers 240 gallons per minute. What is the loss in feet?

Find the column on the upper right of the chart for 6" pipe. Now find "240" under the "U. S. Gallons Per Min." column. Reading across the two columns, you will find that the loss in feet would be 0.87 feet for 100 feet of 6" pipe.

(c) Identify three sections of line in your distribution system. Once you have determined the gallons per minute flow for each section of line, use the Resource Chart to determine the friction loss in feet.

EVALUATION ACTIVITY: You will be expected to determine the friction loss in feet for three different sections of line in your distribution system. You may use the Resource Chart provided with this Competency Sheet.

"HEAD LOSS"*

Loss of Pressure

If only static head were involved in pumping operations, any force exerted by the pump which was greater than the static head (or back pressure) would result in water being pumped. But as soon as water is in motion, there are other factors to be considered. Most important of these factors is friction loss.

There is always friction in any moving body of water. In pressure pipe lines, friction is caused by the water rubbing on the inside surface of the pipe. Friction results in loss of pressure. Friction loss is usually measured in "feet per 100 feet of pipe" and may be easily converted to pressure loss in pounds per square inch.

Pumps are designed to operate under specific head conditions. In addition to the static head, all friction losses and minor losses should be computed in order to determine the total head against which the pump will operate. The pump will then be specially designed, or selected from a standard design, to provide the desired capacity for the conditions under which it will operate. The total pressure provided at the discharge side of the pump represents the discharge pressure of discharge head.

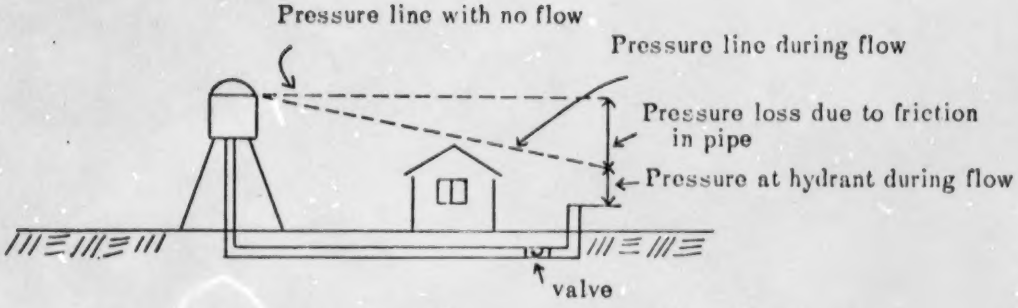
When water flows through a pipe, the water molecules rub against each other and against the wall of the pipe. This is called friction and it requires a pressure to overcome it. The amount of pressure required (or feet of head) to overcome the friction cannot be used for any other purposes and it is therefore called "lost pressure" or "lost head".

Factors Influencing Head Loss in Pipes

Friction loss in a pipe depends on the length of the line, since the head loss varies directly with the pipe length. The rate of flow and condition of the interior surface of the pipe also influence head loss.

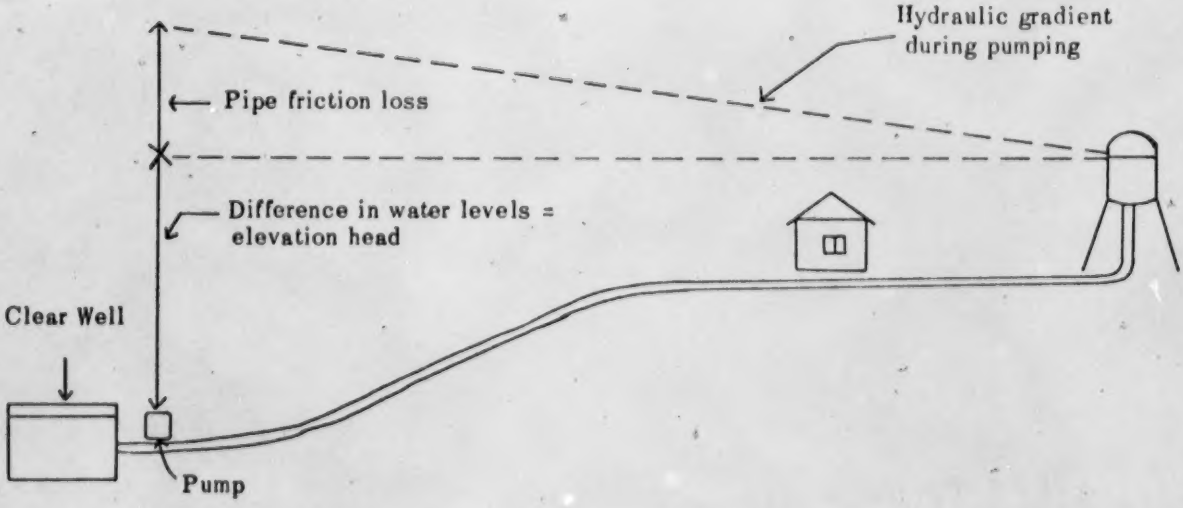
Type of pipe, pipe coating (if any), age of pipe, and the smoothness or roughness of the interior surface of the pipe all affect the carrying capacity of a main through friction loss. A smooth interior surface would result in very little friction loss at a reasonable velocity, whereas a very rough surface would develop a considerable loss through friction, at the same velocity.

*Source: Water Works Operators Manual, Alabama Department of Public Health, Bureau of Environmental Health, Third Edition 1972, Chapter XXVI, pp. 11-15.


Pressure line with no flow
Pressure line during flow
Pressure loss due to friction in pipe
Pressure at hydrant during flow
valve

The pressure lines shown in the above sketch are called hydraulic gradients. The elevation of any point on the hydraulic gradient represents the height to which water would rise due to pressure in the line at a point immediately below the given point on the gradient.

The discharge pressure of a high service pump equals the elevation through which the water is pumped plus pipe friction.



The rate of flow is referred to as velocity, which is the speed at which the water travels through pipe. Velocity is generally measured in "feet per second". Friction loss increases very rapidly as the rate of flow (velocity) through the pipe increases. If the flow through a pipe is doubled, the friction loss in the pipe will be almost four times as great.

The diameter of the pipe also affects the head loss, as the diameter determines the area of wall in contact with flowing water. Also, for a given discharge the diameter determines the velocity of the water.

Increased friction may also be due to any of the following:

a. Sedimentation: mud, silt or sand;
b. Obstruction of the pipe due to debris: sticks, boards, stones, tools, and other things that may have gotten into the pipe during construction;
c. Partly closed valves;
d. Accumulation of air at summits;
e. Mineral deposits and slime growths on walls of pipe;
f. Tuberculation.

There are other minor losses, such as: losses resulting from changes in size of pipe or direction of flow, meter losses, losses through check valves or undersize gate valves, pump friction, etc.

The amount of friction developed is the criterion by which the size of pipe, and the amount of power required for pumping, are determined. When a given amount of water is to be transported, the total amount of friction developed depends on the diameter and length of pipe and the condition of its interior.

In determining the proper size of a new water pipe to be installed in any water distribution system, it is necessary that the main be large enough to deliver the expected demand at adequate pressure. The probable maximum demand must be estimated and should be based on use in other comparable areas. Fire demands may determine size, but these may be exceeded by lawn sprinkling demands in residential areas. Allowance should be made for probably future increases in demand. It may be more economical to anticipate future demand rather than to replace the main with a larger one at some future date.

Mains which serve fire hydrants should not be less than 6 inches in diameter. Mains of smaller size will not be recognized by fire insurance underwriters. Many large cities do not install any mains smaller than 8 inches in size. An 8-inch main costs little more than a 6-inch main to install, since trenching and other costs remain the same. Yet, an 8-inch main has more than twice the capacity of a 6-inch main, under the same head. It is much more desirable to oversize, rather than to undersize, when installing new mains.

When mains are not of sufficient size to meet peak demands in an area, pressures drop rapidly and inadequate service results. Conditions of this nature have been rather prevalent in many cities during the past few years of ever-increasing demands resulting from improved standards of living, rapid population growth, new appliances, air conditioning, and other factors.

The American Water Works Association recommends a normal static pressure of 60 to 75 psi throughout the system. A minimum pressure of 45 psi is desirable in a residential area and 75 psi would be desirable in a commercial or industrial area.

Calculation of Head Loss

There are several formulas for computing the carrying capacities of water mains. The one most commonly used in the water works industry is the Williams and Hazel Formula. A factor called "C" represents the coefficient of friction. It is a measure of the roughness of the interior surface of pipe. A "C" factor of 140 would indicate a very smooth pipe, whereas a "C" factor of 70 would indicate a very rough pipe. The smoother the surface of the pipe wall, the larger the value of "C" and, consequently, the greater the carrying capacity. To save time, these formulas can be converted into chart form, from which head loss values can be read directly. The head loss per 100 feet of pipe is given in the Resource Chart. A good example to show differences in head loss is a flow of 300 gallons per minute in:

a.) 6-inch pipe -13.2feet per 1,000 feet
b.) 8-inch pipe - 3.2 feet per 1,000 feet
c.) 10-inch pipe - 1.1 feet per 1,000 feet

Now compare the above to the same flow of 300 gpm in a 4-inch pipe which results in a head loss of 93 feet per 1,000 feet of pipe.

Problem: A ground storage tank is to be constructed on a hill with an overflow elevation of 586 feet. An 8" line is to be used to serve the town approximately 10,000 feet away from the tank. The elevation of the town is approximately 380 feet.
Find: a.) What fire flow can be expected in the center of town 10,000 feet away while maintaining a 20 psi pressure residual?
b.) With a fire flow of 750 gpm, what will the head loss in the 10,000' of pipe be?
c.) With a fire flow of 750 gpm, what will the pressure residual be at the hydrant in the center of town 10,000 feet from the tank?

Solution:
A. 1.) First find the difference in elevation (i.e., 586' = 380' = 206').
A. 2.) Then determine the feet of head necessary to provide a 20 psi pressure residual. (2.31' of water is equal to

1 pound of pressure, therefore, 20 x 2.31 = 46.2'.)
Therefore, 46.2' of head is necessary.

A. 3.) Subtract this figure from the elevation difference as this head must be constant and maintained at all times. 206' - 46.2' = 159.8'. This 159.8' of head may be used up in friction losses or 1.598' per 100' of pipe may be used.

A. 4.) Referring to the friction loss chart, we see that in an 8" pipe with a head loss of 1.59' per 100' of pipe length that slightly over 700 gpm fire flow can be expected.

B. 1.) Using the table with a 750 gpm fire flow, we find that the friction loss per 100' of pipe is 1.74'.

B. 2.) To find the correct multiplier for the above, we find that $\frac{10,000' \text{ of pipe}}{100' \text{ of pipe}}$ that a multiplier of 100 must be used. Therefore, we then multiply 1.74 x 100 resulting in 174' of frictional head loss in the 10,000 feet of pipe.

C. From the solution in "B" above, we see that 174' of head is lost due to friction. To find the available head and resulting pressure remaining, we subtract 174' from the total elevation difference (head) as found in "A" above or 206'. Therefore, 206' - 174' = 32'. Since 2.31' of head exhibits 1 psi, we divide 32' by 2.31'. This results in a residual pressure of 13.85 psi.

COMPETENCY: Demonstrate the ability to convert pressure measurements from pounds per square inch (psi) to feet of head.

Objective: Describe a situation in your treatment plant where it would be necessary to convert a water pressure measurement from psi to feet of head.

RESOURCES:

(a) "Pressure Measurement" Resource Sheet

(b) Manual of Instruction for Water Treatment Plant Operators, prepared by the New York State Department of Health, Health Education Service, P. O. Box 7283, Albany, New York 12224. Chapter 3. *-Yellow Appendix-*

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find information about converting water pressure measurements.

(b) Determine the water pressure in pounds per square inch (psi) for your water treatment plant's storage tank(s). Using the "Pressure Measurement" Resource Sheet as a reference, convert the pressure in psi to feet of head. Have an experienced operator check your calculations. Practice the conversion process for various water pressures.

EVALUATION ACTIVITY: You will be expected to convert a pressure measurement from psi (pounds per square inch) to feet of head. You may not use references.

"PRESSURE MEASUREMENT"*

Pressures are expressed in terms of force per unit area, such as pounds per square inch or pounds per square foot.

One square foot contains 144 square inches, 12 inches x 12 inches.

Therefore, a pressure of 1 lb/in^2 = 144 lb/ft^2 since every square inch is subjected to a force of one pound.

To calculate the energy per pound of water, you must consider the number of pounds of water in a unit volume. This is called the "density" of water. The density of water is 62.4 lb/ft^3.

If the pressure of the water is lb/in^2 (1 psi), the "pressure head" is:

$$\frac{144\ lb/ft^2}{62.4\ lb/ft^3} = 2.31 \text{ feet}$$

or

1 psi = 2.31 feet presure head

Another example is:

Water pressure of 40 psi equals ...

$$\frac{40 \times 144\ lb/ft^2}{62.4\ lb/ft^3} = 92.4 \text{ feet pressure head}$$

*Source: Manual of Instruction for Water Treatment Plant Operators, prepared by the New York State Department of Health, Health Education Service, P. O. Box 7283, Albany, New York 12224, p. 20.

Operator _____

Evaluator _____

Date _____

Directions: Determine the pressure head in feet for each item below by converting psi to feet of head. Show your calculations.

Example: Pressure measurement = 1 psi

$1\ psi = 144\ lb/ft^2$
$Density = 62.4\ lb/ft^3$

$$\frac{144\ lb/ft^2}{62.4\ lb/ft^3} = 2.31$$

Answer: *1 psi = 2.31 feet pressure head*

1. *69.3 feet* Answer — Pressure measurement = 30 psi

$$\frac{30 \times 144\ lb/ft^2}{62.4\ lb/ft^3} = 69.3\ feet$$

2. *60.06 feet* Answer — Pressure measurement = 26 psi

$$\frac{26 \times 144\ lb/ft^2}{62.4\ lb/ft^3} = 60.06\ feet$$

3. *103.95 feet* Answer — Pressure measurement = 45 psi

$$\frac{45 \times 144\ lb/ft^2}{62.4\ lb/ft^3} = 103.95\ feet$$

BASIC HYDRAULICS*

PRESSURE

Water exerts pressure equally in all directions. This is an important idea to remember and to clearly understand. This principle is illustrated in Figure 1. A balloon is sealed to a tube and held so that the balloon rests lightly on a table. If water is now poured down the tube until the balloon is just full, it takes a more or less round balloon shape. As the tube is filled with water to its top, a foot or two above the top of the balloon, the balloon will expand sideways and take a more flat shape and actually hold more water. This illustrates that the water exerts pressure sideways, as well as vertically, as more water is placed on top of the original amount that filled the balloon only.

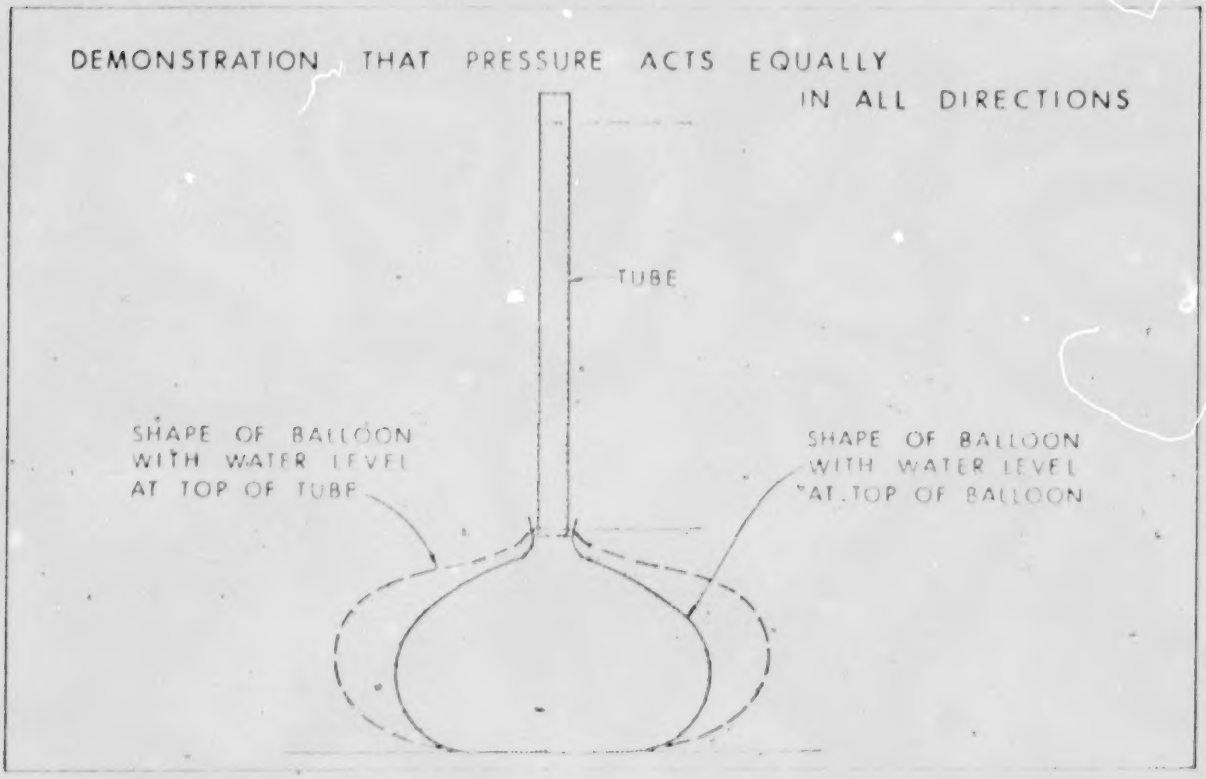


Figure 1 -- PRESSURE ACTS EQUALLY IN ALL DIRECTIONS

*Source: Waterworks Manual - basic, Coordinating Council for Occupational Education, State of Washington, 1972, pp. 49-61, 64-70.

In a water system, pressure is the result of the weight of water in the pipe above the faucet or the point where pressure is being measured. In a tank of water, pressure is greater with greater depth of water, just as a brick lying on a table exerts a force or pressure on the table, but two bricks, one on top of the other, will exert twice as much pressure. Four bricks will exert four times as much pressure or force on the table as one brick. Every layer of the water sustains or holds the weight of the layer or layers above it. This is why we say the pressure of water increases in direct proportion to the depth.

Water weighs 62.4 lb/cu ft, or 8.33 lb/gal. (There are 7.5 gal in 1 cu ft.)

Pressure actually is weight or force given or calculated on the basis of a unit of area. (The unit of area is the square inch.) Thus, if we take a can of water 1 ft square on the bottom and fill it 1 ft deep with water, it will exert a total force on the bottom of 62.4 lb. The pressure, however, or the force on each square inch under the can will be 62.4 divided by 144, or 0.433 lb/sq in. (Pounds per square inch is normally written as psi). The pressure can be increased by pumping such that the height of water, plus the pressure induced by the pump, will determine the pressure at a given point. Unit pressure does not depend on the volume but only on the height of the water. The height of the water that causes the pressure is usually called head. A further illustration of head or pressure can be imagined by considering a 1-in-square tube 10 ft high, which will exert a pressure of 10 times the 0.433 lb exerted by a 1-ft-deep column of water. The pressure at the bottom of the 1-in-square tube will be the same pressure as would occur in a reservoir 100 ft in diameter filled with 10 ft of water. The pressure against the sides of this 100-ft-diameter reservoir at the bottom will also be 10 times 0.433, or 4.33 psi because of the previously described fact that water exerts pressure equally in all directions.

The weight of water will always be very close to 62.4 lb/cu ft, or 8.33 lb/gal, even though pressure or temperature change. Water does not compress or change in volume under pressure as does air.

Pressure is measured in pounds per square inch, or in feet of height of the water column. The pressure is equal to 0.433 times the head of water in feet. Pressure can be measured with a pressure gauge, some of which read in psi and some of which read in feet of head. An example of pressure measurement is shown in Figure 2.

VELOCITY

When a rock is dropped from some height, it falls to the ground due to the force of gravity. Water will also fall to the ground

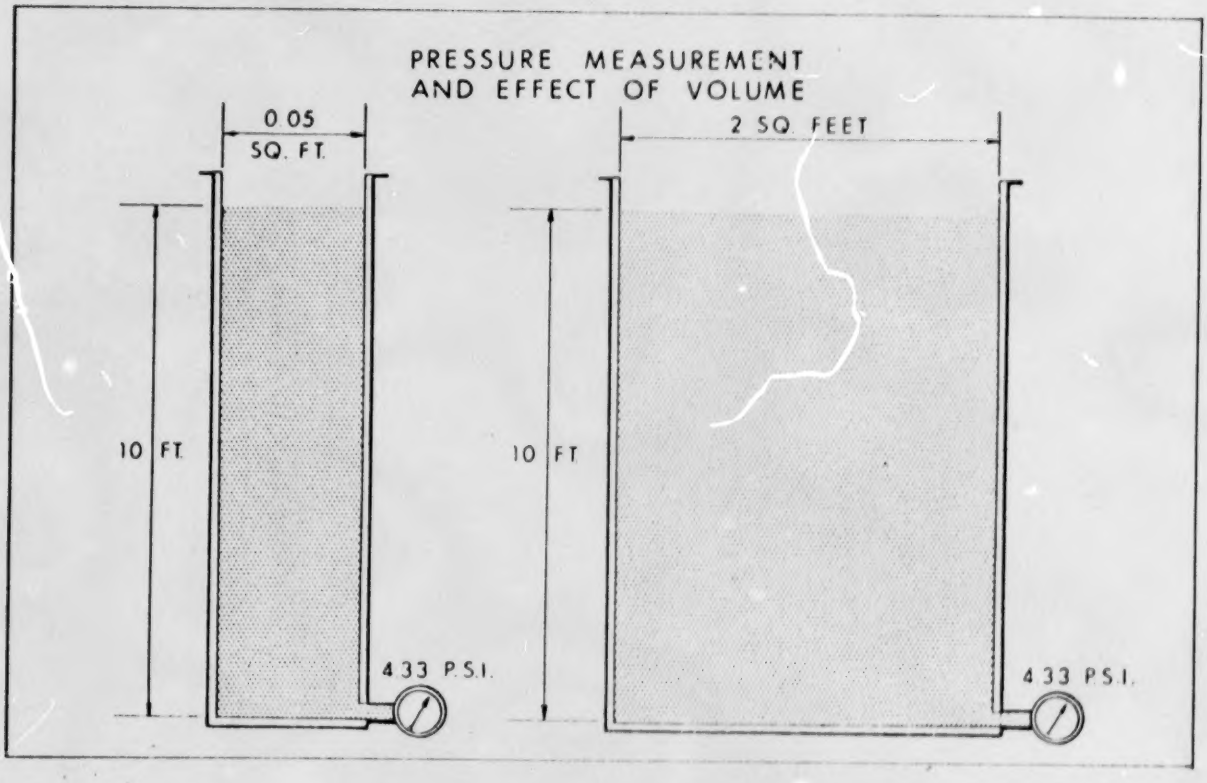


Figure 2 -- PRESSURE MEASUREMENT AND EFFECT OF VOLUME

as a result of this force of gravity. It is the force of gravity that causes water to run downhill, unless it is confined.

The speed at which water will move downhill is called its velocity. Velocity is measured in either miles per hour (mph) or feet per second (fps). A rapidly flowing stream, for example, might move at a velocity of 5 mph, or at 7.3 fps. The velocity of 1 mph is equal to 1.46 fps, or 1 fps is equal to 0.69 mph.

The quantity of water that flows through a pipe or a ditch depends upon this velocity and also on the area of the ditch or pipe at right angles to the direction of flow (Q = VA). For example, a square flume or ditch 1 ft wide and filled 1 ft deep with water would have an area at right angles to the direction of flow 1 sq ft. If the water were flowing in this ditch at a velocity of 1 fps, the quantity flowing would be 1 cu ft/sec (cfs). This 1 cfs would be equal to 7.5 gal/sec since there are

7.5 gal in 1 cu ft. This 1 cfs would also be equal to 60 cu ft/min (cfm), or, multiplying by 7.5 gal/cu ft, it would be equal to 450 gal/min (gpm). Since there are 1,440 min in a day, we can multiply the gallons per minutes times 1,440 and obtain the total gallons flowing in one 24-hr day. One cfs, or 450 gpm, multiplied by 1,440 will give 648,000 gal/day (gpd).

This leads to the obvious and important relation that the quantity of water flowing is equal to the area of the ditch or pipe at right angles to the direction of flow times the velocity. When determining quantity in this way, both the area and the velocity must be expressed in the same units, that is, square feet and feet per second. Normally, the quantity of flow is always calculated in cubic feet per second because area and velocity are expressed in this way, and it is then changed to gallons per minute by multiplying by 450, as explained above, or to gallons per day by multiplying by 648,000.

Some convenient figures to remember in calculating quantity, velocity, and pressure are as follows:

1 cu ft of water weighs 62.4 lb
1 cu ft of water equals 7.5 gal
1 ft of head of water equals 0.433 psi
1 psi equals 2.31 ft of head of water
1 mph equals 1.46 fps
1 fps equals 0.69 mph
1 cfs equals 450 gpm
1 cfs equals 648,000 gpd

FRICTION LOSS

Although water always flows downhill, and appears to do so easily without anything tending to resist or slow down this flow, there is actually friction between the flowing water and the surface of the pipe or ditch in which the water flows. An illustration of this principle is given in Figure 3. Shown in this figure is a tank or reservoir to which is connected a pipe, and at the other end of the pipe a second reservoir is connected. When the second reservoir is held at the same level as the water in the tank, no flow occurs. If the second reservoir is placed 1 ft below the water level in the first tank, water will flow into the second tank.

If we now place the second tank 4 ft below the water level in the first tank, water will flow twice as fast into the second tank as it did before. This illustrates that the friction increases with the rate of flow through the pipe, since the lower tank fills only twice as fast when we increased the difference in elevation or head between the two tanks by four times. Actually, mathematically, the flow in a pipe varies as the square root of the head. In other words, the ratio between the square root of the two heads in the above illustration is equal

to the square root of the ratio between the two rates of flow. This can be checked with a stopwatch by actually timing the number of seconds required to fill the second tank at the two different elevations. To state this idea in another way, the loss of head or friction loss due to flow in the pipe changes as the square of the quantity of flow. In other words, if we wish to obtain twice as much flow through a pipe, we must increase the available head between the two ends of the pipe by four times.

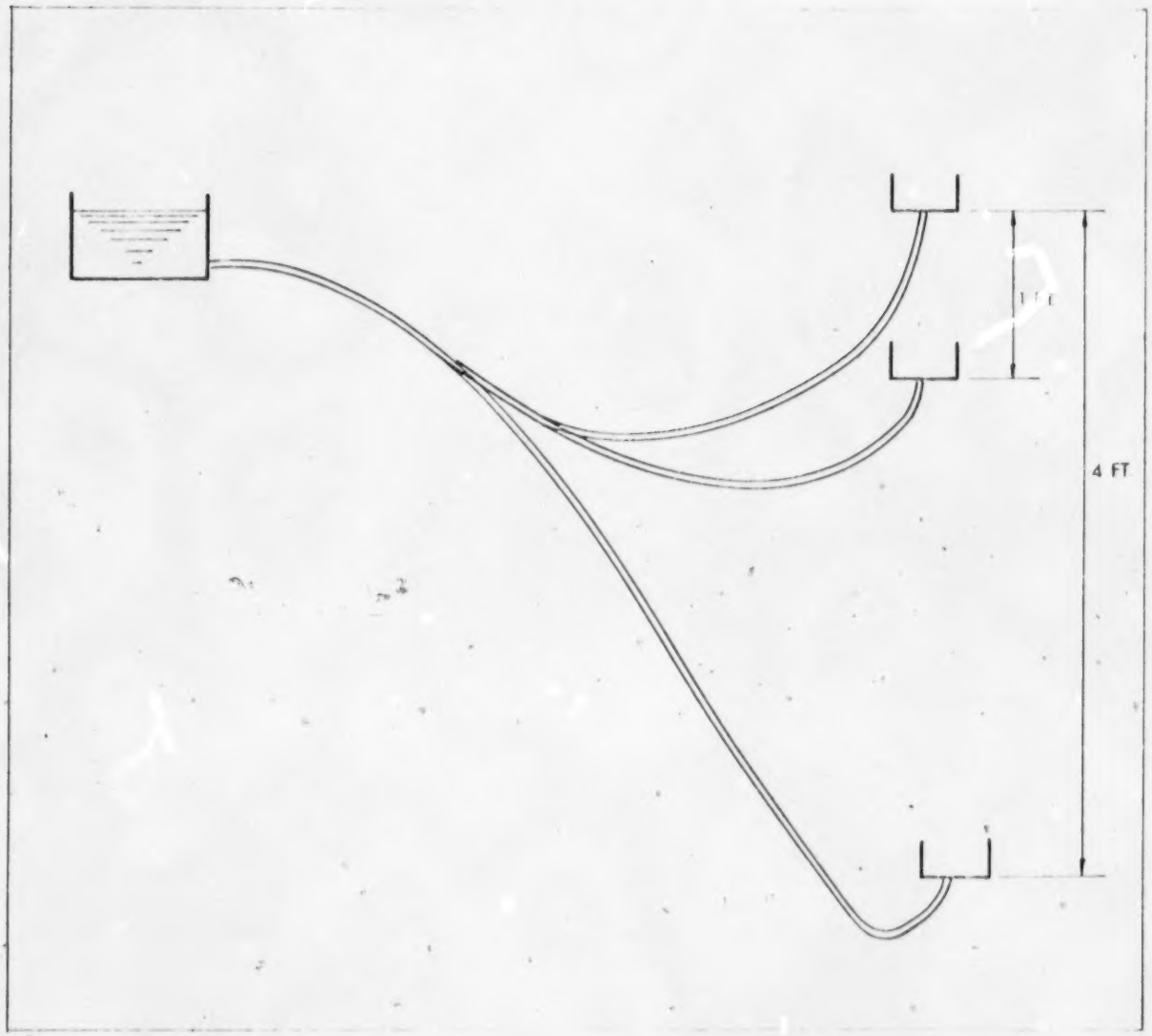


Figure 3 -- FRICTION IN PIPELINES

TABLE I

FRICTION LOSS OF WATER PER 100 FEET LENGTH OF PIPE (INSIDE DIAMETER)

Based on Williams & Hazen Formula Using Constant 100

Sizes of Standard Pipe in Inches

½" Pipe		¾" Pipe		1" Pipe		1¼" Pipe		1½" Pipe		2" Pipe		2½" Pipe		3" Pipe		4" Pipe		5" Pipe		6" Pipe		U.S. Gals. Per min.
Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	
2.10	7.4	1.20	1.9																			2
4.21	27.0	2.41	7.0	1.69	2.11	.86	.57	.63	.26													4
6.31	57.0	3.61	14.7	2.23	4.55	1.29	1.20	.94	.56	.81	.20											6
8.42	98.0	4.81	25.0	2.98	7.8	1.72	2.01	1.26	.95	.82	.33	.52	.11									8
10.52	147.0	6.02	38.0	3.72	11.7	2.14	3.01	1.57	1.43	1.02	.50	.65	.17	.45	.07							10
		7.22	53.0	4.46	16.4	2.57	4.3	1.89	2.01	1.23	.74	.78	.23	.54	.10							12
		9.02	80.0	5.80	25.0	3.21	6.5	2.35	3.06	1.53	1.08	.98	.36	.68	.15							15
		10.84	108.2	6.69	35.0	3.86	9.1	2.83	4.24	1.84	1.49	1.18	.50	.82	.21							18
		12.03	136.0	7.44	42.0	4.29	11.1	3.15	5.20	2.04	1.81	1.31	.61	.91	.25	.51	.06					20
				9.30	66.0	5.35	16.9	3.89	7.30	2.55	2.71	1.63	.92	1.13	.38	.64	.09					25
				11.15	89.0	6.43	23.0	4.73	11.0	3.06	3.84	1.96	1.29	1.36	.56	.77	.13	.49	.04			30
				13.02	119.0	7.51	31.2	5.51	14.7	3.57	5.10	2.29	1.72	1.59	.71	.89	.17	.57	.06			35
				14.88	157.0	8.58	40.0	6.30	18.8	4.08	6.6	2.61	2.20	1.82	.91	1.02	.22	.65	.08			40
						9.65	50.0	7.08	23.2	4.60	8.2	2.94	2.80	2.04	1.15	1.15	.28	.73	.09			45
						10.72	60.0	7.87	28.6	5.11	9.6	3.27	3.32	2.27	1.38	1.28	.34	.82	.11	.57	.04	50
						11.78	72.0	8.66	36.0	5.62	11.8	3.59	4.01	2.45	1.59	1.41	.41	.90	.14	.62	.05	55
						12.87	85.0	9.45	39.6	6.13	13.9	3.92	4.65	2.72	1.92	1.53	.47	.98	.16	.68	.06	60
						13.92	99.7	10.23	41.9	6.64	16.1	4.24	5.4	2.89	2.16	1.66	.53	1.06	.19	.74	.076	65
								15.01	113.0	11.02	53.0	7.15	18.4	4.58	6.2	3.18	2.57	1.79	.63	1.14	.21	.79	.08	70
								16.08	129.0	11.80	60.0	7.66	20.9	4.91	7.1	3.33	3.00	1.91	.73	1.22	.24	.85	.10	75
								17.16	145.0	12.59	68.0	8.17	23.2	5.23	7.9	3.63	3.28	2.04	.81	1.31	.27	.91	.11	80
								18.21	163.8	13.38	75.0	8.68	26.6	5.56	8.1	3.78	3.54	2.17	.91	1.39	.31	.96	.12	85
								19.30	180.0	14.71	86.0	9.19	29.4	5.86	9.8	4.09	4.08	2.30	1.00	1.47	.34	1.02	.14	90
										14.95	91.0	9.70	32.6	6.21	10.8	4.22	4.33	2.42	1.12	1.55	.38	1.08	.15	95
8" PIPE										15.74	107.0	10.21	35.8	6.54	12.0	4.54	4.96	2.55	1.22	1.63	.41	1.13	.17	100
										17.33	122.0	11.23	42.9	7.18	14.5	5.00	6.0	2.81	1.46	1.79	.49	1.25	.21	110
										18.89	141.0	12.25	50.3	7.84	16.8	5.45	7.0	3.06	1.17	1.96	.58	1.36	.24	120
										20.46	160.0	13.28	58.0	8.48	18.7	5.91	8.1	3.31	1.92	2.12	.67	1.47	.27	130
.90	.08									22.04	180.0	14.30	67.0	9.15	22.3	6.35	9.2	3.57	2.28	2.29	.76	1.59	.32	140
.96	.09											15.32	76.0	9.81	25.5	6.82	10.5	3.82	2.62	2.45	.88	1.70	.36	150
1.02	.10											16.35	86.0	10.46	29.0	7.26	11.8	4.08	2.91	2.61	.98	1.82	.40	160
1.08	.11	10" PIPE										17.36	96.0	11.11	34.1	7.71	13.3	4.33	3.26	2.77	1.08	1.92	.45	170
1.15	.13											18.38	107.0	11.76	39.7	8.17	14.0	4.60	3.61	2.94	1.22	2.04	.50	180
1.21	.16											19.40	119.0	12.42	39.6	8.63	15.5	4.86	4.01	3.10	1.35	2.16	.55	190
1.28	.15											20.42	131.0	13.07	43.1	9.08	17.8	5.11	4.44	3.27	1.48	2.27	.62	200
1.40	.18	.90	.06									22.47	156.0	14.38	52.0	9.99	21.3	5.62	5.2	3.59	1.77	2.50	.73	220
1.53	.21	.98	.07									24.51	182.0	15.69	61.0	10.89	25.1	6.13	6.2	3.92	2.08	2.72	.87	240
1.66	.25	1.06	.08									26.55	211.0	16.99	70.0	11.80	29.1	6.64	7.2	4.25	2.41	2.95	1.00	260
1.79	.29	1.15	.09											18.30	81.0	12.71	33.4	7.15	8.3	4.58	2.77	3.18	1.14	280
1.91	.32	1.22	.11											19.61	92.0	13.62	38.0	7.66	9.3	4.90	3.14	3.40	1.32	300
2.05	.37	1.31	.12	10" PIPE										20.92	103.0	14.57	42.8	8.17	10.5	5.23	3.56	3.64	1.47	320
2.18	.41	1.39	.16											22.22	116.0	15.43	47.9	8.68	11.7	5.54	3.97	3.86	1.62	340
2.30	.45	1.47	.15			12" PIPE								23.53	128.0	16.34	53.0	9.19	13.1	5.87	4.41	4.08	1.83	360
2.43	.50	1.55	.17	1.08	.061									24.84	142.0	17.25	59.0	9.69	14.0	6.19	4.86	4.31	2.00	380
2.60	.54	1.63	.19	1.14	.073									26.14	156.0	18.16	65.0	10.21	16.0	6.54	5.4	4.55	2.20	400
2.82	.66	1.84	.23	1.28	.93											20.40	78.0	11.49	19.8	7.35	6.7	5.11	2.74	450
3.19	.82	2.04	.28	1.42	.113	1.16	.06									22.70	98.0	12.77	24.0	8.17	8.1	5.68	2.90	500
3.52	.97	2.24	.33	1.56	.135	1.35	.91									24.96	117.0	14.04	28.7	8.99	9.6	6.25	3.96	550
3.86	1.14	2.45	.39	1.70	.159	1.42	.06									27.23	137.0	15.32	33.7	9.80	11.3	6.81	4.65	600
4.16	1.34	2.65	.45	1.84	.19	1.53	.09											16.59	39.0	10.62	13.2	7.38	5.40	650
4.46	1.54	2.86	.52	1.99	.22	1.64	.10											17.87	44.9	11.44	15.1	7.95	6.21	700
4.80	1.76	3.06	.59	2.13	.26	1.76	.11	16" PIPE										19.15	51.0	12.26	17.2	8.50	7.12	750
5.10	1.90	3.26	.66	2.27	.27	1.87	.13											20.42	57.0	13.07	19.4	9.08	7.96	800
5.48	2.20	3.47	.75	2.41	.31	1.99	.14	1.36	.05									21.70	64.0	13.89	21.7	9.65	8.95	850
5.75	2.46	3.67	.83	2.56	.34	1.88	.16	1.44	.06	20" PIPE								22.98	71.0	14.71	24.0	10.20	10.11	900
6.06	2.87	3.88	.91	2.70	.38	2.00	.18	1.52	.07											15.52	26.7	10.77	11.20	950
6.38	4.97	4.08	1.03	2.84	.41	2.10	.19	1.60	.10	1.02	.04									16.34	29.2	11.34	12.04	1000
7.03	3.52	4.47	1.19	3.13	.49	2.31	.24	1.76	.12	1.12	.04									17.97	34.9	12.48	14.55	1100
7.66	4.17	4.90	1.40	3.41	.58	2.52	.27	1.92	.14	1.22	.05									19.61	40.9	13.61	17.10	1200
8.30	4.85	5.31	1.62	3.69	.67	2.71	.32	2.08	.17	1.33	.06											14.72	18.4	1300
8.95	5.50	5.71	1.87	3.98	.75	2.92	.36	2.24	.19	1.43	.07	24" PIPE										15.90	22.60	1400
9.58	6.24	6.12	2.13	4.26	.89	3.13	.41	2.39	.21	1.53	.07											17.02	25.60	1500
10.21	7.00	6.53	2.39	4.55	.98	3.34	.47	2.56	.24	1.63	.08			30" PIPE								18.10	26.9	1600
11.50	8.78	7.35	2.95	5.11	1.21	3.75	.56	2.87	.30	1.84	.10	1.28	.04											1800
12.78	10.71	8.16	3.59	5.68	1.49	4.17	.71	3.19	.37	2.04	.12	1.42	.05											2000
14.05	12.75	8.98	4.26	6.25	1.81	4.59	.84	3.51	.44	2.25	.15	1.56	.06											2200
15.32	14.2	9.80	5.04	6.81	2.08	5.00	.93	3.83	.52	2.45	.17	1.70	.07	1.09	.02									2400
		10.61	5.81	7.38	2.43	5.47	1.17	4.15	.60	2.66	.20	1.84	.08	1.16	.022									2600
		11.41	6.70	7.95	2.75	5.84	1.32	4.47	.68	2.86	.23	1.98	.09	1.27	.03									2800
		12.24	7.62	8.52	3.15	6.01	1.49	4.79	.78	3.08	.27	2.13	.10	1.37	.032									3000
		13.05	7.8	9.10	3.51	6.68	1.67	5.12	.88	3.27	.30	2.26	.12	1.46	.041									3200
		14.30	10.08	9.95	4.16	7.30	1.97	5.59	1.04	3.59	.35	2.49	.14	1.54	.04									3500
		15.51	13.4	10.80	4.90	7.98	2.36	6.07	1.20	3.88	.41	2.69	.17	1.73	.05									3800
				11.92	5.88	8.76	2.77	6.70	1.46	6.29	.49	2.99	.20	1.91	.07									4200
				12.78	6.90	9.45	3.22	7.18	1.66	4.60	.56	3.20	.22	2.04	.08									4500
				14.20	8.40	10.50	3.92	8.01	2.01	5.13	.68	3.56	.27	2.26	.09									5000
						11.55	4.65	8.78	2.38	5.64	.82	3.90	.33	2.50	.11									5500
						12.60	5.50	9.58	2.79	6.17	.95	4.25	.38	2.73	.13									6000
						13.65	6.35	10.34	3.17	6.6	1.10	4.61	.45	2.96	.15									6500
						14.80	7.08	11.18	3.60	7.23	1.25	4.97	.52	3.18	.17									7000
								12.04	4.11	8.17	1.61	5.68	.66	3.64	.21									8000
								12.91	5.30	8.70	2.01	6.15	.81	4.08	.28									9000
								13.90	7.19	10.00	2.44	7.07	.98	4.55	.33									10000
										11.3	3.61	8.50	1.50	5.46	.49									12000
										13.20	4.54	9.93	1.87	6.37	.63									14000
												11.34	2.40	7.28	.81									16000
												12.76	2.97	8.18	1.02									18000
												14.20	3.60	9.10	1.23									20000

Friction in a pipeline actually depends upon the velocity or rate of flow, upon the size of the pipe (that is its diameter or area), and upon the roughness of the surface of the inside of the pipe. This roughness friction is denoted in hydraulics by the C-factor. When the statement is made that a pipe friction loss is calculated on the basis of C equals 100, the statement means that it is based on a certain roughness of the pipe that causes a given amount of friction. A C-factor of 100 would apply to very rough, old pipe. New, smooth coal tar or cement-lined pipe has a C-factor of 100 to 140.

Head losses or friction losses for 100-ft lengths of pipe of varying sizes, with C-factors of 100, are tabulated in Table I. For example, to determine how much head loss would occur in 100 feet of 2-in pipe for a flow of 100 gpm, go down the "U. S. Gals. Per Min." column to 100; then move across to the left to the "Loss in Feet" column for 2-inch pipe. There you will find that the head loss is 35.8 ft.

TABLE II

C-FACTOR MULTIPLIERS

C	40	60	80	90	100	110	120	130	140
K	5.46	2.58	1.51	1.22	1.00	0.838	0.713	0.615	0.536

Remembering the conversion factors discussed previously, this 35.8 ft multiplied by 0.433 psi per foot of head gives a pressure loss of 15.5 psi. Thus, if the pressure in the main where a 2-in tap is made is 50 psi, the pressure 100 ft away at the point where a service might enter a house, for example, would only be 34.5 psi (50 - 15.5) when the flow through the service is 100 gpm. The friction loss would be twice as much for 200 ft of pipe and 10 times as much for 1,000 ft of pipe. Thus, the friction loss for lengths of pipe other than 100 ft is found by multiplying the values in Table I by the number of 100-ft lengths of pipe through which the water actually flows.

Friction losses can be used to determine the size of service pipe required for a given requirement for water. A similar procedure can be used to determine the loss in transmission pipelines to establish the size required to bring water in from a reservoir, say, to the main part of the distribution system in a city. Table I has been included to give a ready means of estimating the amount of friction loss or pressure loss in pipes for given quantities of flow.

CONSERVATION OF HEAD

Another important factor to be considered in the hydraulics of pipelines is the principle of conservation of head. Basically, this idea is based on the fact that water at a certain elevation, such as water in a reservoir on a high hill, has energy. This is readily believed when a reservoir breaks and the water flows out of it down the hill, because the energy the water has in moving down the hill is very damaging and destroys much property. This energy due to position or elevation can be changed to other forms, but it cannot be destroyed.

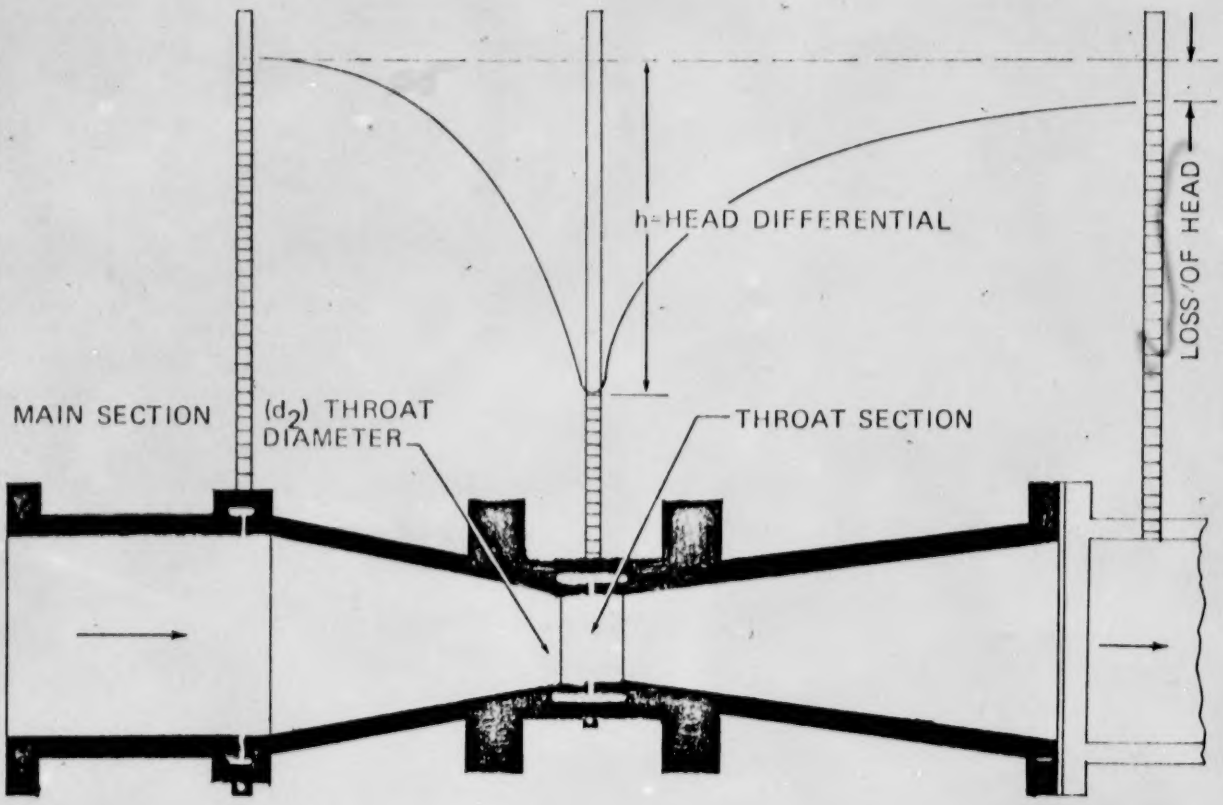
Some energy is required to start water to move, in other words, to give it velocity. For example, in the illustration described in Figure 3, if we measured the pressure in the pipeline immediately outside the upper or first reservoir when water is flowing, we would find that it is slight less than the pressure just inside the reservoir. This is because a certain amount of pressure, which is energy, has been required to get the water into motion. This is based on the basic principle originally developed by Newton that a body or a fluid will not change its condition of rest unless a force is applied. A force is required to start the water moving downhill.

The portion of the basic energy in water that is used to overcome friction to move the water through a pipe or along a ditch is actually burned up or used up in heating the water and therefore cannot be recovered. It is possible, however, to recover the energy or head used in getting the water started in motion by stopping it again carefully so that friction and turbulence do not occur. Thus, except for friction losses, the total energy in a body of water is always the same, although some of it may be energy of position and some may be energy of motion.

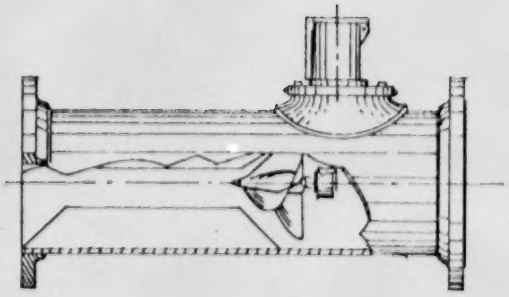
FLOW MEASUREMENT

Quantity of flow is measured by several devices. The simplest of these is the propeller meter. This device consists simply of a propeller quite similar to the propeller used on a boat or outboard motor. It is set in the pipeline and turns at a rate proportional to the velocity of the water flowing through the pipe. By the proper calibration of this type of meter, it will read in gallons per minute and also record the total number of gallons or cubic feet that pass the meter.

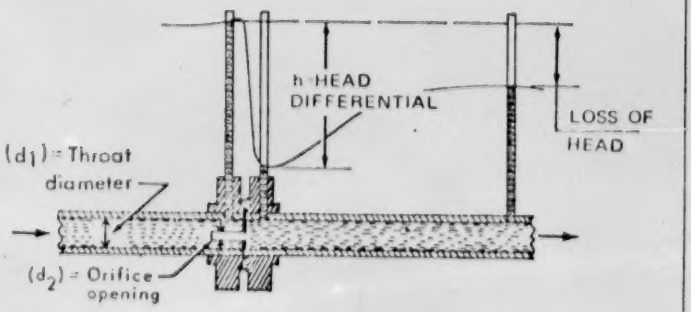
A Venturi-type meter is a different device, and it actually is based on the principle of conservation of head discussed previously. The venturi tube is a necking down of a pipe as illustrated in Figure 4, which shows a typical venturi meter. The velocity of the water must increase through the neck of the venturi or throat, as it is called, since the total amount of flowing must be the same and the area of the pipe is reduced at the throat. By measuring the change in pressure or head



VENTURI



PROPELLER



ORIFICE

Figure 4 -- COMMON METER TYPES

between the pipe at its original size and in the throat, it is possible to determine the velocity at which the water is flowing. From this, the quantity of flow can be determined using the areas involved. Most of the change in head or pressure necessary to increase the velocity at the throat can be recovered again by the recovery section, which is tapered on the downstream side of the throat.

An orifice operates on the same general theory as the venturi, since it is a plate with a hole causing reduction in the pipe area at right angles to the flow, but the head cannot be completely recovered due to the fact that it does not have a recovery section.

Weirs are devices used to measure flow in channels or streams. If the flow of water can be dammed or controlled so that it passes through or over the weir at one point, this method of measurement is relatively simple. The usual weir is a rectangular notch cut in the top of the dam with a sharp edge on the upstream side. If the depth of water flowing upstream from this notch is known, the quantity of flow in cubic feet per second or gallons per minute can be calculated from a mathematical formula. Figure 5 shows a typical rectangular weir and tabulates the flows for various depths of water flowing through the weir opening. Other shapes of weirs, such as triangular and trapezoidal, are also used, and tables for the flow can be obtained from hydraulic handbooks.

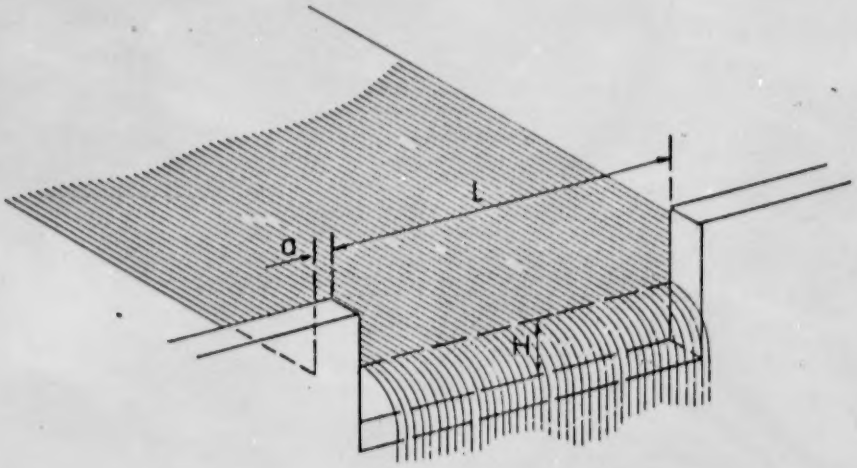
WATER TRANSMISSION HYDRAULICS

Water transmission involves the transporting or moving of water from the basic source to the point of use or to the distribution system in the case of a public water system.

FRICTION LOSSES

It is the friction losses that determine the size and capacity of transmission pipelines from the source of supply to the distribution system.

To be able to determine flow of water in transmission lines, the idea of hydraulic gradient must be understood. The hydraulic gradient is nothing more than the imaginary line to which water would rise if we could construct standpipes along a transmission line high enough to allow the water to rise as high as it could. If the pipe is uniform in size and there are no branch lines or takeoffs along the line, then this hydraulic gradient, or imaginary line to which the water will rise, will be a straight line. The slope of this line determines the quantity of flow. Figure 6 is a typical example of a pipeline of different sizes of pipe with a gradient that is a straight line along each section of pipe of one size, but the gradient changes in slope, that is, it becomes steeper as the pipe becomes smaller.



Figures in Table are in Gallons Per Minute								
Head (H) in Inches	Length (L) of weir in feet				Head (H) in Inches	Length (L) of weir in feet		
	1	3	5	Additional g.p.m. for each ft. over 5 ft.		3	5	Additional g.p.m. for each ft. over 5 ft.
1	38.4	107.5	179.9	36.05	8	2338	3956	814
1¼	49.5	150.4	250.4	50.4	8¼	2442	4140	850
1½	64.9	197	329.5	66.2	8½	2540	4312	890
1¾	81	248	415	83.5	8¾	2656	4511	929
2	98.5	302	506	102	9	2765	4699	970
2¼	117	361	605	122	9¼	2876	4899	1011
2½	136.2	422	706	143	9½	2985	5098	1051
2¾	157	485	815	165	9¾	3101	5288	1091
3	177.8	552	926	187	10	3216	5490	1136
3¼	199.8	624	1047	211	10¼	3450	5940	1230
3½	222	695	1167	236	11	3718	6355	1320
3¾	245	769	1292	261	11½	3960	6780	1410
4	269	846	1424	288	12	4185	7185	1495
4¼	293.8	925	1559	316	12½	4430	7595	1575
4½	318	1006	1696	345	13	4600	8010	1660
4¾	344	1091	1835	374	13½	4950	8510	1780
5	370	1178	1985	405	14	5215	8980	1885
5¼	395.8	1262	2130	434	14½	5475	9440	1985
5½	421.6	1352	2282	465	15	5740	9920	2090
5¾	449	1442	2440	495	15½	6015	10400	2165
6	478.5	1535	2600	528	16	6290	10900	2300
6¼		1632	2760	560	16½	6565	11380	2410
6½		1742	2930	596	17	6925	11970	2530
6¾		1826	3094	630	17½	7140	12410	2640
7		1928	3260	669	18	7410	12980	2745
7¼		2029	3436	701.5	18½	7695	13410	2855
7½		2130	3609	736	19	7983	13940	2970
7¾		2236	3785	774	19½	8280	14460	3090

This table is based on Francis formula

$Q = 3.33 (L - 0.2H) H^{1.5}$

which

Q = cu. ft. of water flowing per second.

L = length of weir opening in feet. (should be 4 to 8 times H).

H = head on weir in feet (to be measured at least 6 ft. back of weir opening)

a = should be at least 3 H.

Figure 5 -- DISCHARGE FROM RECTANGULAR WEIR WITH END CONTRACTIONS

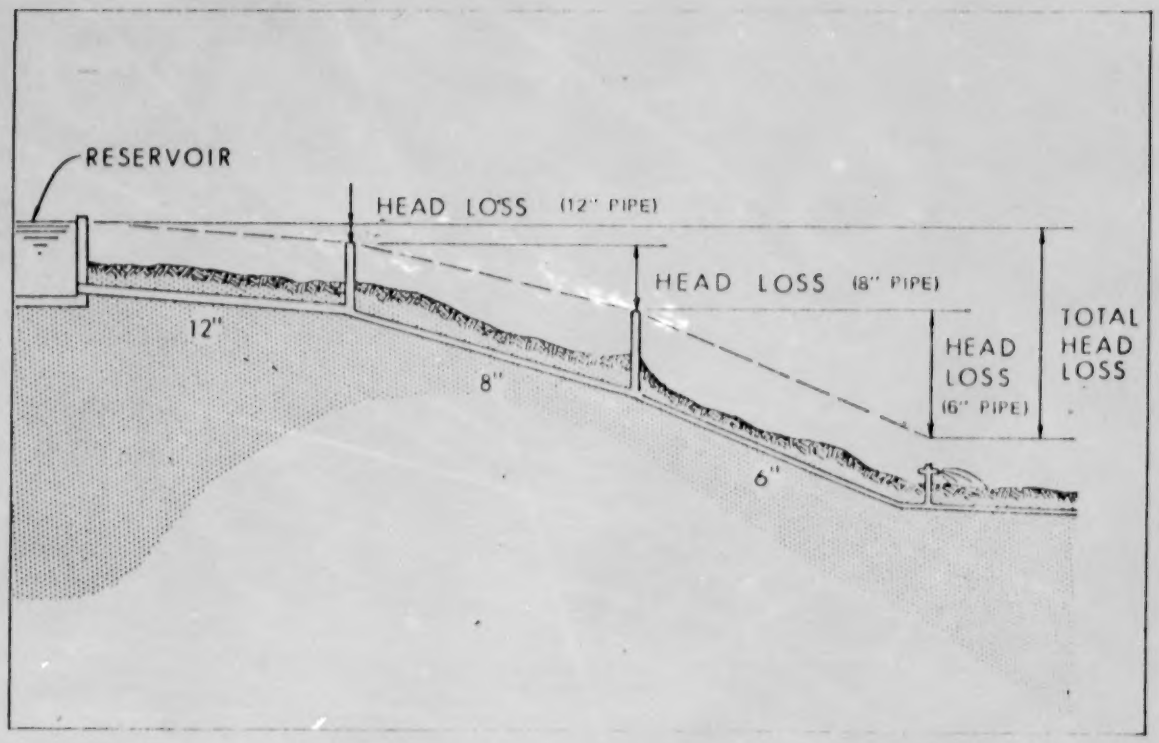


Figure 6 -- HEAD LOSS DUE TO FRICTION IN TRANSMISSION PIPELINE

This slope or the steepness of this gradient line, which represents the elevation to which water would rise in a standpipe, is determined by the head loss, as given in Table I.

HYDRAULIC FORCES

Since transmission pipelines are normally under pressure, that is, the water is confined in the pipe under a considerable head, there are forces that tend to move or act upon the pipe itself. For example, if the pipe is under pressure, and remembering that water exerts pressure equally in all directions, the pressure has a tendency to stretch, or to expand the pipe, and the pipe must be strong enough to resist this internal pressure or tendency to expand.

When there is a closed valve at the end of line under pressure, the pressure of the water is applied to the valve. Unless the valve is blocked, shackled, or fastened to the pipeline through flange bolts, it will blow off. Similarly, if a riser is placed

in the line and a plug is placed on the end of the riser, the plug will blow off unless it is strong enough to resist the pressure of the water against it.

Wherever in a transmission pipeline there is a change in direction, there is an unbalanced force that tends to move the pipe. If we consider a 90° bend in a pipeline and think of it as actually a square bend, there will be a pressure against the bend that will tend to blow the bend off the remainder of the pipe. This pressure will act upon the area of the pipe diameter and in the direction in which the bend surface of the pipe faces. The actual calculation of the force against a 90° bend, or against any other bend, is a somewhat complicated problem in trigonometry involving a resolution of forces acting at angles. It should be realized that a change in the vertical direction will cause a thrust as well as will a change in the horizontal direction. Therefore, all bends must be anchored. The usual method for anchoring bends in which the unbalanced thrust is upward is to fasten sufficient concrete to the pipeline to counteract the uplift force. In the case of horizontal bends, the pipe is normally blocked against undisturbed earth so that it cannot move. An examination of the amount of the force listed in Figure 7 will give adequate indication of the need for careful anchorage of pipelines at bends. Sometimes this is hard for the uninitiated to realize, but anyone who has worked with water pipelines very long has experienced this force when an improperly anchored bend has moved under pressure. The amount of concrete required to anchor a horizontal bend depends on the strength of the undisturbed soil. The methods of placing concrete to keep the joint accessible are shown in Figure 7. The area in square feet of concrete that must bear against the side of the trench is found by dividing the thrust in pounds as shown in Figure 7 by the safe bearing load of the soils. Safe bearing loads of soil for horizontal thrusts when the depth of cover over the pipe exceeds 2 ft are shown in Table III.

SAFE BEARING LOADS

Soil	*Safe Bearing Load (psf)*
Muck, peat, etc.[a]	0
Soft clay	1,000
Sand	2,000
Sand and gravel	3,000
Sand and gravel cemented with clay	4,000
Hard shale	10,000

[a] In muck or peat, all thrusts are resisted by piles or tie rods to solid foundations or by removal of muck or peat and replacement with ballast of sufficient stability to resist thrusts.

TABLE III

Thrust at Fittings in Pounds Due to Water Pressure

Size	Pressure psi	Tees Dead Ends	90 deg. Bend	45 deg. Bend	22½ deg. Bend
3"	100	1220	1720	931	474
	150	1830	1880	1020	519
	200	1610	2270	1230	628
4"	100	1940	2750	1490	759
	150	2020	2860	1550	790
	200	2350	3330	1800	919
6"	100	3830	5420	2930	1500
	150	4100	5800	3140	1600
	200	4750	6710	3630	1850
8"	100	6580	9310	5040	2570
	150	6980	9870	5340	2720
	200	7910	11200	6050	3090
10"	50	9830	13900	7510	3830
	100	10300	14600	7890	4020
	150	11300	15900	8620	4400
	200	12300	17400	9450	4810
12"	50	13900	19600	10600	5390
	100	14600	20600	11200	5700
	150	15900	22500	12200	6210
	200	17200	24400	13200	6720
14"	50	18600	26300	14300	7270
	100	19800	28000	15200	7740
	150	21600	30600	16500	8440
	200	23300	32900	17800	9080
16"	50	24000	33900	18400	9370
	100	25700	36300	19700	10000
	150	27800	39400	21300	10900
	200	30300	42800	23200	11800
18"	50	30000	42400	23000	11700
	100	32300	45600	24700	12600
	150	35000	49500	26800	13700
	200	38300	54100	29300	14900
20"	50	36700	51900	28100	14300
	100	39700	56100	30300	15500
	150	43000	60800	32900	16800
	200	47400	67000	36300	18500
24"	50	52300	74000	40000	20400
	100	56800	80300	43500	22200
	150	61700	87300	47200	24100
	200	66200	96400	52200	26600
30"	50	82400	117000	63100	32200
	100	88200	125000	67500	34400
	150	96700	137000	74000	37700
	200	106000	150000	81100	41400
36"	50	118000	167000	90400	46100
	100	127000	179000	96900	49400
	150	139000	197000	107000	54300
	200	152000	215000	116000	59300

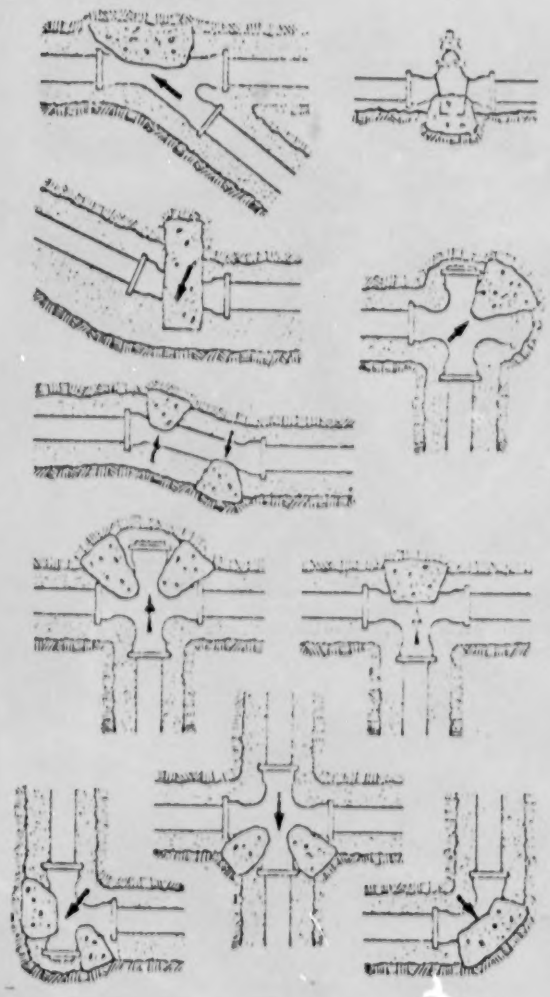


Figure 7 -- THRUST AT PIPE FITTINGS

In addition to the normal pressure exerting a force, a valve closed too rapidly causes the water to come to a sudden stop, thus causing a high pressure or thrust. This is called a "water hammer". Where this is likely to occur, additional blocking will be required (see Figure 8).

Additional deficiency points may be assigned because of unusual climate conditions as well as for an excessive difference between class of water supply and class of fire department that would make it impossible to use the better class to full value.

The required fire flow in high-value districts for average municipalities is given in Table IV. Also shown is the required duration of the fire flow and the recommended average area served per hydrant in the high-value district. In residential areas composed of single-family, one-story dwellings located on large lots, 500 to 1,000 gpm would be the minimum fire flow required, with a fire flow duration of 2 to 6 hr. All fire flows are the flows available at the fire hydrants with a 20 psi pressure in the water main adjacent to the hydrant (see Table IV).

NETWORK HYDRAULICS

The quantity of water that can be delivered by the distribution system depends on the network of pipes interconnected to form the distribution grid, the topography (or elevation differences) of the area to be served, the head (or pressure) available to force water through the distribution system, and the location of the water supply source and storage reservoirs with respect to the areas of maximum water use. All of these considerations are important and must be studied together to determine the capacity of the distribution system.

FLOW IN PIPES

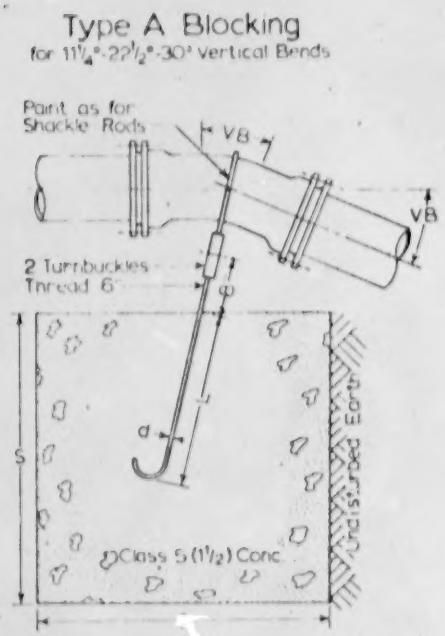
The quantity of water a given pipe can carry depends on the size and type of pipe, the age and condition of the pipe, the length of pipe, and the head available. Table I gives head loss for various sizes of pipe and rates of flow.

The mathematical formula for determining pipe size is difficult to use in ordinary calculations; therefore, Table I has been prepared as a timesaver device. The table is based on a C-factor of 100, and will apply to pipes with considerable interior roughness. This C-factor is an experimentally determined measure of the roughness of the interior of the pipe.

Problem: A 6-in. diameter pipe is 3,000 ft. long and is to carry 450 gpm. What head loss will result?

Type "A" Blocking
for 11¼°-22½°-30° Vertical Bends

Pipe Size Nom. Diameter-Inches	Test Pressure psi	VB Vertical Bend Degrees	No of cu ft of Conc Blocking	S Side of Cube feet	d Diameter of Shackle Rods (2) inches	L Depth of Rods in Concrete feet
4"	300	11¼	8	2	¾	15
		22½	11	2 2		20
		30	17	2 6		
6"	300	11¼	11	2 2	¾	20
		22½	25	2 9		
		30	41	3 5		
8"	300	11¼	16	2 5	¾	20
		22½	47	3 6		
		30	70	4 1	¾	25
12"	250	11¼	32	3 2	¾	20
		22½	88	4 5	⅞	30
		30	132	5 1		
16"	225	11¼	70	4 1	⅞	30
		22½	184	5 7	1	40
		30	275	6 5	1¼	
20"	200	11¼	91	4 5	⅞	30
		22½	225	6 1	1¼	40
		30	330	6 9	1⅜	45
24"	200	11¼	128	5 0	1	35
		22½	320	6 8	1⅜	45
		30	480	7 9	1½	55



Type "B" Blocking
for 45° Vertical Bends

Pipe Size Nom. Diameter-Inches	Test Pressure psi	VB Vertical Bend Degrees	No of cu ft of Conc Blocking	S Side of Cube feet	d Diameter of Shackle Rods (4) inches	L Depth of Rods in Concrete feet
4"	300	45	30	3 1	¾	20
6"			68	4 1		
8"			123	5 0		
12"	250		232	6 1	¾	25
16"	225		478	7 8	1⅛	40
20"	200		560	8 2	1¼	
24"			820	9 4	1⅜	45

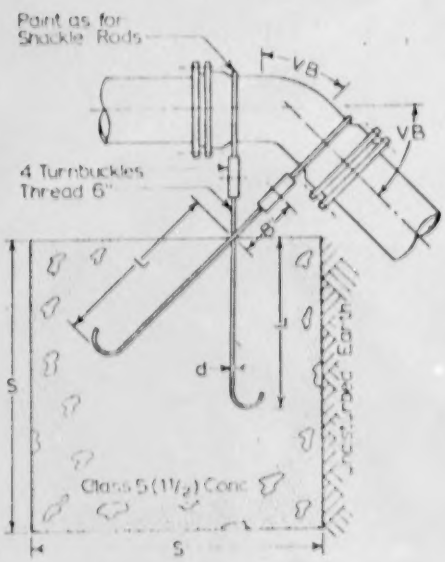


Figure 8 -- BLOCKING

TABLE IV

REQUIRED FIRE FLOW AND HYDRANT SPACING TO CONFORM TO THE AMERICAN INSURANCE ASSOCIATION

Population[a]	*Required Fire Flow for Average City (gpm)*	*Duration (hr)*	*Recommended Average Area Served per Hydrant in High-Value District (sq ft)*
1,000	1,000	4	120,000
1,500	1,250	5	.....
2,000	1,500	6	.....
3,000	1,750	7	.....
4,000	2,000	8	110,000
5,000	2,250	9	.....
6,000	2,500	10	.....
10,000	3,000	10	100,000
13,000	3,500	10	.....
17,000	4,000	10	90,000
22,000	4,500	10	.....
27,000	5,000	10	85,000
33,000	5,500	10	.....
40,000	6,000	10	80,000
55,000	7,000	10	70,000
75,000	8,000	10	60,000
95,000	9,000	10	55,000
120,000	10,000	10	48,000
150,000	11,000	10	43,000
200,000	12,000	10	40,000

[a] Over 200,000 population, 12,000 gpm, with 2,000 to 8,000 gpm additional for a second fire, for a 10-hr duration.

Solution: Check in Table I under 6-in pipe and find head loss is 2.74 ft/100 ft. For 3,000 ft. of lenght, then,

$$\text{head loss} = \frac{3,000}{100} \times 2.74$$

$$= 82.2 \text{ ft.}$$

If any two of the four interrelated facts describing the pipe flow conditions are known, the other two may be found from the table. For a given pipe diameter, quantity of flow and velocity are dependent only upon each other; but head loss per unit of length is dependent upon the pipe diameter, quantity of flow, and condition of pipe. To determine the head loss for C values other than 100, refer to Table II and multiply the loss of head obtained from Table I by the appropriate K for the C-factor desired. In the above example, if C had been 120 instead of 100, the head loss would have been (0.713)82.2 = 58.6 ft. K is a correction factor that adjusts the head loss for C = 100 to the correct head loss for any other value of C.

PIPES IN SERIES -- Consider two pipes connected in series, as shown in Figure 9. The quantity of water passing through both pipes is the same, but the head losses are quite different.

Referring to Table I and assuming the pipes both have C-factors of 100, the head losses are as follows:

For D = 8 in., head loss A-B = 1.5 ft
For D = 4 in., head loss B-C = 44 ft

Total head loss from the point marked A to the point marked C is the sum of the head losses from point A to point B and from point B to point C, resulting in a total head loss from A to C of 45.5 ft. It should also be noted that, if all other conditions are similar, doubling the pipe diameter will reduce head losses by about 97%.

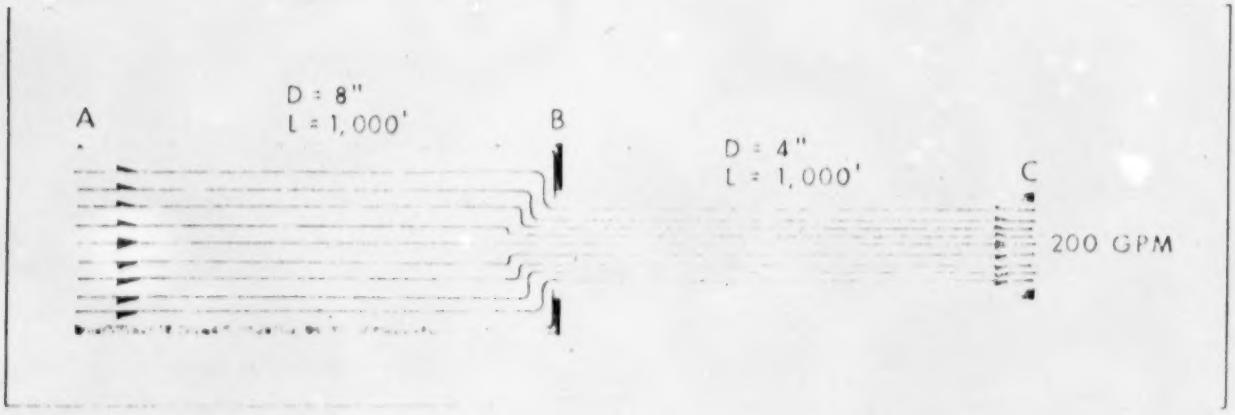


Figure 9 -- PIPES IN SERIES

The 2,000-ft-long pipe system from A to C is capable of delivering 200 gpm from A to C with a head loss of 45.5 ft. Any other pipe (or pipes) that would deliver 200 gpm from A to C with the same 45.5 ft of head loss could be substituted for the 4-in and 8-in pipe and would be considered an "equivalent" pipe. The reader should verify that 7,339 ft of 6-in pipe or 256 ft of 3-in pipe would both be considered equivalent to the 2,000 ft of 8-in and 4-in pipe of the original problem.

PIPES IN PARALLEL -- Consider the pipes connected in parallel, as shown in Figure 10. The head loss from A to C is the same regardless of the route taken, but the quantity of flow through pipes ABC is quite different from the flow through pipes AEC. The flow entering at A is the same as the flow leaving C.

The pipe system ABC is similar to the example of the previous section on pipes in series. Let us assume that the head loss from A to C is 45.5 ft for this example of parallel pipes. The pipe system ABC can then be replaced with its equivalent pipe, 7,339 ft of 6-in pipe.

With a total head loss of 45.5 ft, 7,339 ft of 6-in pipe will transmit 200 gpm through route ABC, while 5,000 ft of 10-in pipe will transmit 950 gpm through route AEC. Total flow entering at A and leaving at C must then be 1,150 gpm. We can now replace pipes ABC and AEC with a single "equivalent" pipeline, AC, that will transmit 1,150 gpm with a total head loss of 45.5 ft.

The equivalent-pipe process is a convenient tool to reduce a complex distribution system into a simpler network of pipes that can be studied effectively. In parallel pipe systems, the total head loss must be equal for all possible routes, while in series pipe systems, the total quantity flow must be constant.

NETWORK GRIDS

The distribution system serving the consumers consists of the following.

SUPPLY MAINS -- The supply mains are the direct conveyers of water from the source to various sections of the city. They are of large diameter and should be interconnected by mains of liberal size at intervals of a mile or so and equipped with blowoffs at low points and air relief valves at high points. No district should depend upon a single main.

ARTERIAL SYSTEM -- The arterials consist of secondary feeders connecting to the supply mains. They must be of sufficient size to deliverthe fire flow and domestic supply necessary for the district and must be frequently spaced (about every 3,000 ft) and looped.

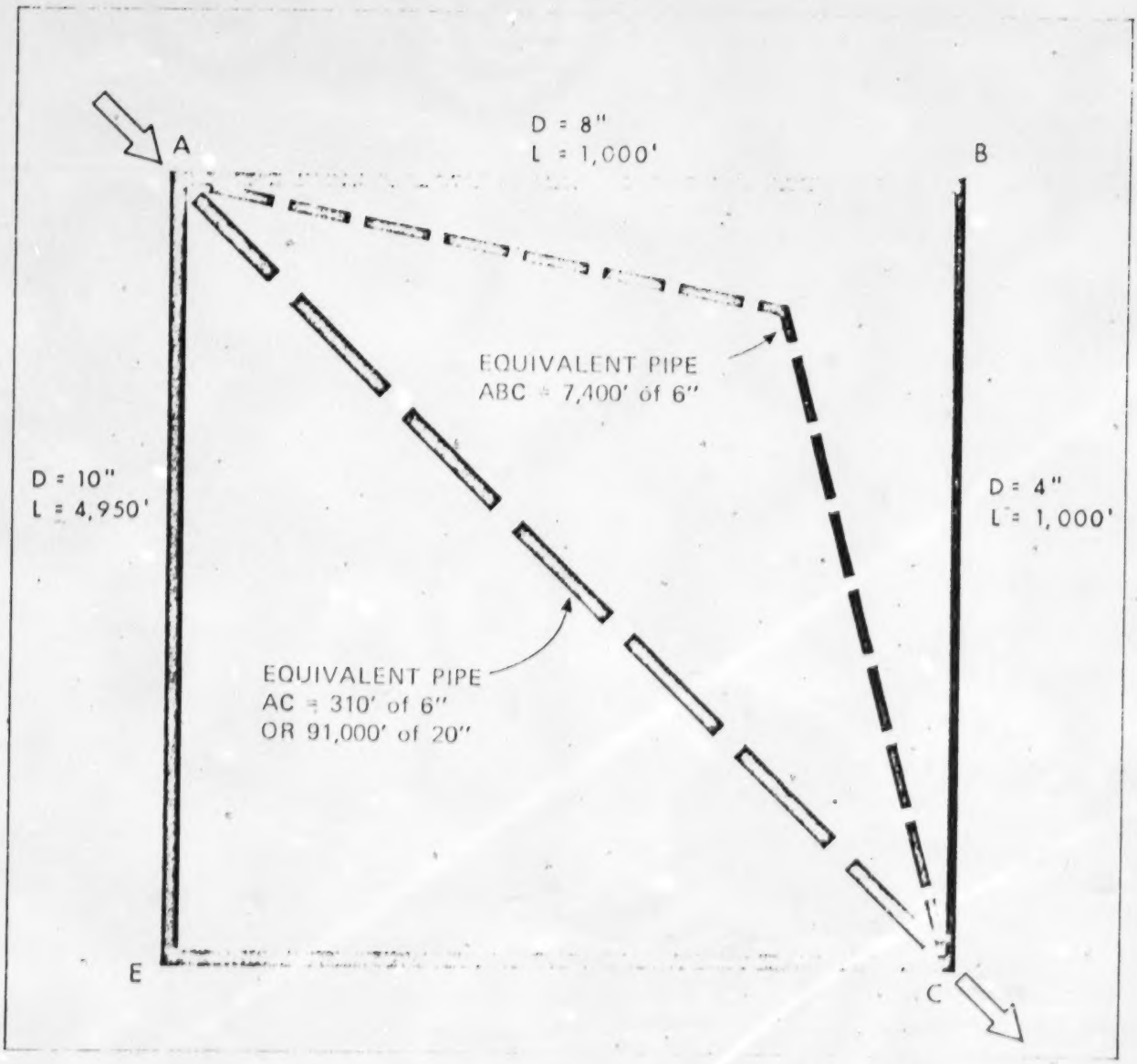


Figure 10 -- PIPES IN PARALLEL

MINOR DISTRIBUTORS -- The minor distributors make up the gridiron of pipes between the secondary arterials and they also supply the fire hydrants. This does not, however, preclude the use of 4-in pipe for side streets where domestic consumption only will be supplied. The minor distributors should be gridironed with 6-in pipes at intervals not exceeding 600 ft, although, if pressures are good, larger cross-connecting pipes may be used at greater intervals. In high-value districts, the minimum size should be 8-in, with cross pipes for each 600 ft interval. On the principal streets, 12-in or larger mains are recommended and also for all long lines not frequently interconnected.

VALVES -- The importance of valves is frequently overlooked, both in design of new systems and extensions and in maintenance. A sufficient number of properly located valves is a necessity for operation and control of the pipe system. Figure 11 shows a typical distribution system grid with valves located so that any pipe can be isolated without interrupting service to more than two city blocks of customers. A third valve at each intersection would cut the interrupted service area in half.

HYDRANTS -- The hydrants should be spaced at intervals that will not require more than about 300 ft of hose to be used between the hydrant and the fire. Good hydrant distribution would be to place a hydrant at each street intersection as shown on Figure 11 below.

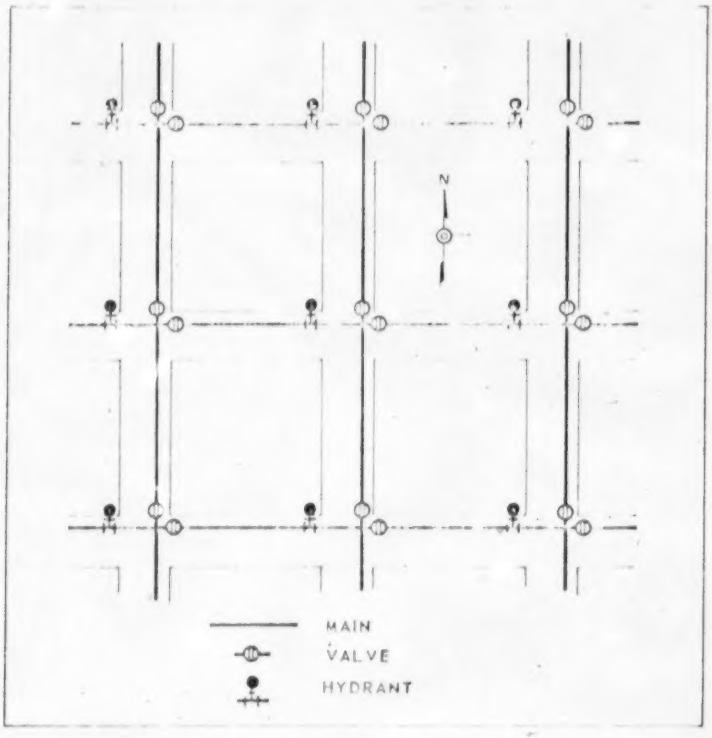


Figure 11 -- TYPICAL DISTRIBUTION GRID LAYOUT

PRESSURE REQUIREMENTS

The capacity of a distribution system is not only based on the ability to furnish the necessary flow of water to various points in the system, but also on the pressures necessary to develop such flows and to furnish each customer with sufficient pressure at his connection to satisfy his normal requirements.

Normal pressures in a distribution system under average conditions of flow should range between 50 and 80 psi. Topography of the service area has much to do with the maintenance of good pressures throughout the system. When the area is very hilly with considerable range of elevation, it becomes nearly impossible to maintain a standard pressure that will not be too high in the low areas or too low in the elevated areas. Pressures in excess of 100 psi should preferably be eliminated, but sometimes they cannot be avoided. It is wise when such high pressures result to have the individual customers provide pressure-reducing valves to limit the pressures to 100 psi or less.

It might be pointed out that excess pressures promote pipeline failures and excess leakage losses. The losses resulting from increased leakage and, in most part, the cost of repairing mains that may be broken when the pressures are increased are usually more than offset by the increased revenues that result from better registration of meters and increased use due to the higher pressures, particularly when the system is substantially fully metered.

HYDRAULICS*

There are similarities between fluids and electricity which help to understand the fundaments of both. For example, we have the following units of measurement:

	Fluid	*Electricity*
Pressure	pounds per square inch (psi) or feet of water	electromotive force (emf) E or volts
Flow	gallons per minute (gpm) or cubic feet per second (cfs)	amperes (amp)
Resistance to flow	head loss feet of fluid or psi	resistance (ohms)
Quantity	gallons or cubic feet (gal) or (cf)	kilowatt hours (KWH)

Hydraulics

This is the name given to that branch of science which deals with fluids at rest and in motion. The former is sometimes spoken of as hydrostatics and the latter as hydrodynamics. We are concerned here mainly with water at rest and in motion. Many of the same principles apply to air and gases.

Consideration will be given to water moving or flowing through pipes, channels and pumps and ways of measuring the quantity flowing in a given time. We must be careful of units, the basic ones being:

Length in feet	ft
Area in square feet	sq ft or ft^2
Rate: gallons per minute	gpm
million gallons per day	mgd
cu ft per second	cfs or sec ft
Weight: 1 gallon of water	8.34 lb
1 cu ft water	62.4 lb
Speed or velocity of flow in feet per second	ft/sec

*Source: Manual of Instruction for Water Treatment Plant Operators, prepared by the New York State Department of Health, Health Education Service, P. O. Box 7283, Albany, New York 12224, pp. 19-38.

Head. The precise meaning of the term *head* is the amount of energy possessed by a unit quantity of water at its given location. Ordinarily, the energy is expressed in *foot-pounds*, and the unit quantity of water considered is one pound. The head, then, is expressed in foot-pounds of energy per pound of water, or,

$$\frac{\text{ft X lb}}{\text{lb}} = \text{ft}$$

Thus, all heads can be expressed in feet. Water may contain energy due to (a) its elevation, (b) its pressure, or (c) its velocity. These energies are called elevation (or static) head, pressure head, and velocity head, respectively. In addition, operators often have occasion to refer to *pump head*, which is the energy required for a pump to move one pound of water, and to *friction head*, which is the energy lost due to friction within the fluid and against the walls of the pipe or channel.

Elevation (or static) head. Elevations must be expressed as the vertical distance from some base level, or reference plane, such as mean sea level, the surface of the ground, or some other arbitrarily chosen level.

Then, for example, water that is 100 feet above the reference plane, has 100 ft-lbs of energy, and its elevation head is 100 feet.

Pressure head. Pressures are expressed in terms of force per unit area, such as pounds per square inch or pounds per square foot. One square foot contains 144 square inches. Therefore, a pressure of 1 lb/in^2 = 144 lb/ft^2, since every square inch is subjected to a force of one pound.

To calculate the energy per pound of water, we must consider the number of pounds of water in a unit volume, which is called the "density" of the water. The density of water is 62.4 lb/ft^3. Then if the pressure of the water is 1 lb/in^2 (often written 1 psi), the "pressure head" is

$$\frac{144\ lb/ft^2}{62.4\ lb/ft^3} = 2.3\ ft.$$

or

1 psi = 2.3 ft pressure head

By the same kind of calculation, a water pressure of 40 psi equals

$$\frac{40 \times 144\ lb/ft^2}{62.4\ lb/ft^3} = 92.3\ ft \text{ pressure head}$$

or

40 x 2.3 = 92.3 ft pressure head

Velocity head. The energy of motion is called kinetic energy and is calculated by the relationship

$$\text{Energy} = \frac{mv^2}{2g}$$

where m represents the weight of the moving object, v its velocity, and g the force which gravity exerts on a mass of one pound.

In everyday speech, we are accustomed to expressing both force and mass in pounds. However, this causes confusion when energy calculations are attempted, bacause the force exerted by gravity is not numerically equal to the mass in pounds. That is to say, force and mass cannot properly be expressed in the same units.

One way of avoiding this difficulty is to speak of the force of gravity in terms of the acceleration it produces when it acts upon a unit mass. One of the fundamental laws of physics is that force equals mass times acceleration. Thus, the force on a unit mass of one pound is numerically equal to the acceleration.

Acceleration is the rate at which velocity changes. If an automobile goes from zero miles per hour to sixty miles per hour in two minutes, we can say that its average change of speed was thirty miles per hour in each minute, or thirty miles per hour per minute. Likewise, if water moving ten feet per second speeds up to fifteen feet per second, and the time required for the change of speed is one second, we could say that it accelerated five feet per second per second. Accelerations are often expressed in feet per second. The units can then be written ft/sec. This is equivalent to writing $\frac{\text{ft}}{\text{sec x sec}}$ or $\frac{\text{ft}}{\text{sec}^2}$

When gravity acts upon a free-falling body, it produces an acceleration of 32.2 ft/sec^2. This value of g can be used in the equation for calculating velocity head. If we consider, for example one pound of water moving with a velocity of 10 ft/sec, its velocity head is calculated as follows:

$$\text{Energy} = \frac{1 \text{ lb} \times 10 \text{ ft/sec} \times 10 \text{ ft/sec}}{2 \times 32.2 \text{ ft/sec}^2} = 1.55 \text{ ft-lb}$$

$$\text{Velocity head} = \frac{1.55 \text{ ft-lb}}{1 \text{ lb}} = 1.55 \text{ ft}$$

In the first of these two equations, we multiplied by the weight of the water. In the second, we divided by the weight of the water. Since these two operations cancel each other, the velocity head can be calculated by leaving out the weight in the first place:

$$\text{Velocity head} = \frac{v^2}{2g}$$

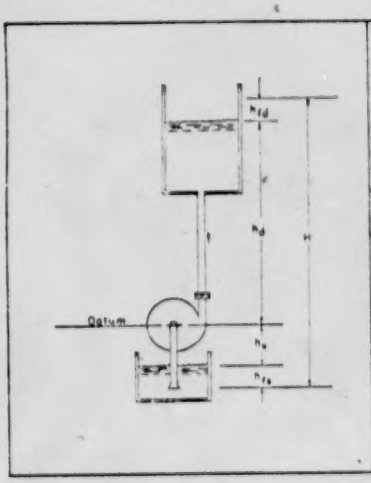
Friction head. Friction head equals the loss of energy due to friction within the liquid and friction against the walls of the pipe or channel. When we are dealing with water, the friction

within the liquid is relatively small, and most of the energy is lost due to friction against the walls. Therefore, the friction loss depends mostly upon the characteristics of the material of which the pipe or channel is made and its surface smoothness. The usual procedure for estimating friction head losses is to use a table in an engineering handbook which gives directly the friction loss per foot of a particular kind of pipe or channel.

Pump head. The pump head equals the ft-lb of energy given to each pound of water passing through the pump.

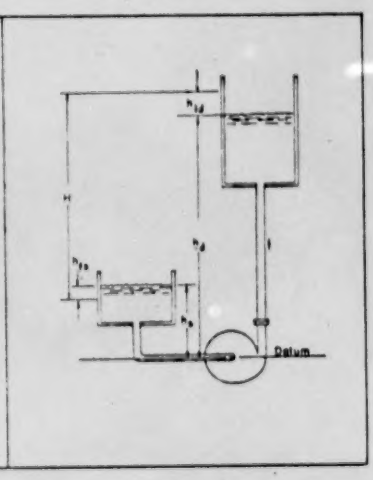
Pumping. Pumps are used to move liquids to a higher level or to increase the rate of flow. Figure (8) and Figure (9) show two typical pumping conditions. To understand these figures it is necessary to know that in a liquid at rest, the pressure at any point is equal to the weight of the liquid above the point, plus the weight of the atmosphere above the surface of the liquid.

FIG. 8



PUMP
WITH SUCTION LIFT

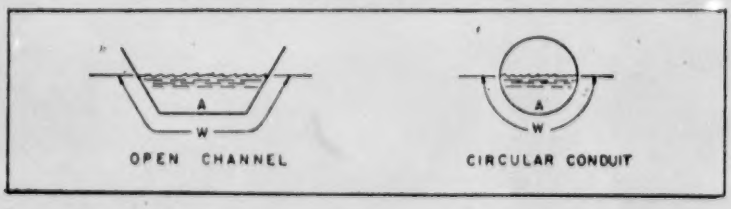
FIG. 9



PUMP
WITH SUCTION HEAD

Both must be expressed in the same units. These units are usually pounds per square inch (psi) or feet of water. Since most pumping problems involve differences in pressure, the atmospheric pressure may be neglected and gauge pressures (psig) or height in feet may be used. Total head in feet at a point can be expressed as the height of a column of water whose weight would produce a certain pressure at that point. Psi x 2.31 = head in feet.

FIG. 10



HYDRAULIC
RADIUS

HYDRAULIC RADIUS

For Figure 8 -- Pump operating with a suction lift:

$$H = h_d + h_s + h_{fd} + h_{fs} + \frac{V^2_d}{2g} \frac{V^2_s}{2g}$$

For Figure 9 -- Pump operating with suction head:

$$H = h_d - h_s + h_{fd} + h_{fs} + \frac{V^2_d}{2g} \frac{V^2_s}{2g}$$

Where --

H = Total head in feet (formerly called total dynamic head) at which the pump operates.

h_d = Static discharge head in feet, or the vertical distance between the pump datum and liquid surface in the receiving tank. The pump datum is at the center line for horizontal pumps and at the entrance eye of the impeller for vertical pumps.

h_s = Static suction head or lift in feet or vertical distance between pump datum and liquid surface in the suction well.

h_{fd} = Friction head in discharge in feet or the head necessary to overcome friction in valves, fittings, etc. in the discharge piping.

h_{fs} = Friction head in suction in feet.

g = 32.2 ft/sec^2 = Acceleration due to gravity.

$\frac{V^2_d}{2g}$ and $\frac{V^2_s}{2g}$ discharge nozzle and suction nozzle of the pump. When the nozzles are of the same diameter, these values are equal and cancel out. Velocity head represents energy which the pump must deliver to the liquid but which is not measured by a pressure gage. It is the head required to give to the liquid the velocity "V" in feet per second.

The relationship between the volume of water flowing per unit of time, the velocity of the moving water and the size of pipe or channel through which the flow takes place may be expressed by the equation:

$$Q = AV$$

Where = Q = rate of flow or volume per unit time (usually expressed as cubic ft/sec (cfs)

A = Area through which water is flowing, measured at right angles in the direction of flow (usually expressed in sq ft)

V = Average velocity of flow or distance traveled per unit of time (usually expressed as ft/sec)

There are three general types of problems using the equation $Q = AV$. These are as follows:

1. The water in an open channel has been observed to flow a distance of 180 feet in 2 minutes. The dimensions of the channel are 2 feet wide and 18 inches deep. Compute the rate of flow

$$V = \frac{180 \text{ ft}}{2 \text{ min}} = \frac{90 \text{ ft}}{\text{min}} = \frac{1.5 \text{ ft}}{\text{sec}}$$

$$A = 2 \text{ ft} \times 18 \text{ in} \times \frac{\text{ft}}{12 \text{ in}} = 3.0 \text{ sq ft}$$

then

$$Q = AV = 3.0 \text{ sq ft} \times \frac{1.5 \text{ ft}}{\text{sec}} = 4.5 \text{ cfs}$$

2. A meter shows water flowing through a 12-inch diameter pipe at the rate of 2 mgd. To determine the velocity of the water

$$Q = \frac{2{,}000{,}000 \text{ gal}}{\text{day}} \times \frac{\text{cu ft}}{7.5 \text{ gal}} \times \frac{\text{day}}{24 \text{ hr}} \times \frac{\text{hr}}{60 \text{ min}} \times \frac{\text{min}}{60 \text{ sec}} = 3.08 \text{ cf}$$

$$A = \pi r^2 = 3.1416 \times 6 \text{ in} \times 6 \text{ in} \times \frac{\text{sq ft}}{144 \text{ sq ft}} = 0.79 \text{ sq ft}$$

$$\text{then } V = Q/A = \frac{3.08 \text{ cu ft}}{0.79 \text{ sq ft} \times \text{sec}} = 3.9 \frac{\text{ft}}{\text{sec}}$$

3. Baffles are to be placed in a coagulation tank so that the velocity of flow between baffles is 0.3 ft/sec. The depth of flow in the tank is 8 feet and the rate of flow through the tank is 2 mgd. Find the distance, w between baffles.

$$Q = 2\text{mgd} \times 1.55 \frac{\text{cfs}}{\text{mgd}} = 3.08 \text{ cfs}$$

$$V = 0.3 \text{ ft/sec}$$

let the distance between baffles equal w

$$\text{then } A = 8 \times w = \frac{Q}{V} = 3.08 \frac{\text{cu ft}}{\text{sec}} \times \frac{\text{sec}}{0.3 \text{ ft}}$$

$$w = \frac{3.08 \text{ cu ft/sec}}{8 \text{ ft} \times 0.3 \text{ ft/sec}} = 1.28 \text{ ft}$$

Pipe Friction. The h_{fd} and h_{fs} in the preceding paragraphs are those portions of the total head necessary to overcome friction between the fluid and the walls of the suction and discharge piping. The values of these terms depend upon the length of the pipeline, its diameter, the velocity of the flowing liquid and the condition of the internal walls of the pipe, usually called the roughness factor.

These influences are expressed in the formula

$$h_f = \text{Friction head} = f \frac{L}{d} \frac{V^2}{2g}$$

Where f = roughness factor
L = length of pipe
d = diameter
$\frac{V^2}{2g}$ = velocity head

Tables are available for the value of f, which varies with both V and d in this formula. The value of f is fractional, varying from .04 for small V and d to .01 for large values of V and d. Another formula derived from this basic one expresses the roughness factor as a whole number known as the C value in the Hazen & Williams formula. Tables and a special slide rule have been developed for solving pipe problems by this formula. The value of C varies from 140 for very smooth large pipe to a low of 40 or less for badly corroded or dirty pipe. See Figure 11 (Flow Chart for value "C" equals 100).

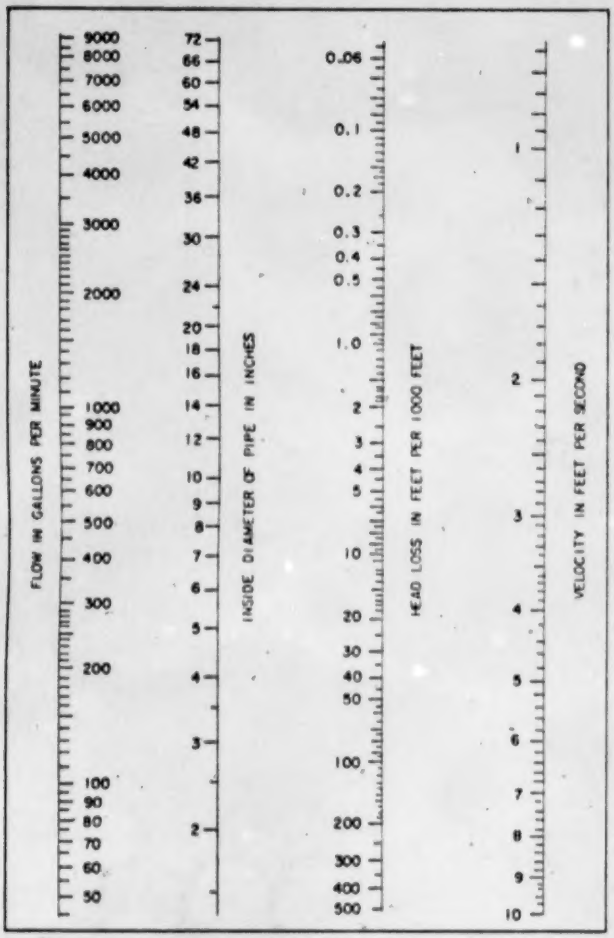
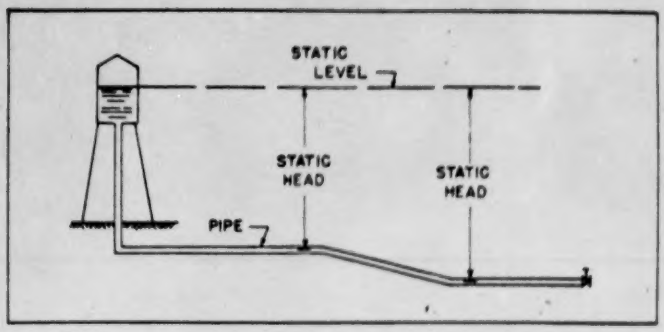


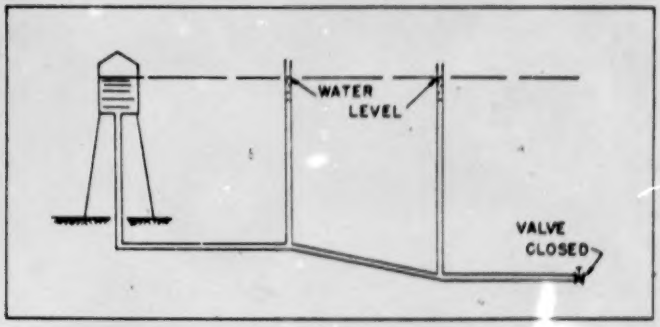
Figure 11

FLOW CHART
"C" = 100
Based on the Hazen-Williams Formula

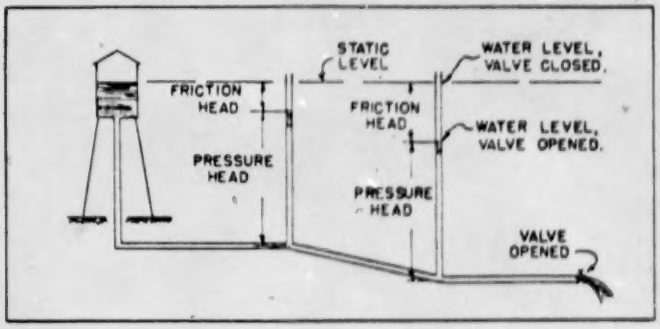
FIG. 12



STATIC HEAD



WATER LEVEL, NO FLOW IN PIPE



PRESSURE HEAD

If vertical open pipes are attached in a pipe line as shown in Figure 12, the water level in the pipes will stand at a level even with the elevation of the water in the storage tank. If the outlet valve is opened to permit water to flow, the level of the water in the vertical pipes will drop. The drop in the level or loss in head is the "friction head" and represents the energy lost by friction of the water flowing through the pipe.

Power Requirements for Pumping. Work must be done to move liquid against the total heads (H) indicated in Figures 8 and 9. The unit of work is the foot pound which is the amount of work or energy required to lift one pound a vertical distance of one foot. The common unit of power or rate of doing work is horsepower (hp). One horsepower is equal to 33,000 ft. lbs. per minute. In electrical units, one horsepower is equivalent to 746 watts.

The power required to drive a pump can be computed as follows:

Work done by the pump (or water horsepower) = Whp

$$Whp = \frac{\text{lbs. of water raised per minute} \times H}{33{,}000}$$

$$= \frac{gpm \times 8.34 \times H}{33{,}000} = \frac{gpm \times H}{3{,}960}$$

Example: The sum of the elevation, pressure, velocity and friction heads is 100 feet. What would be the work done by the pump or the horsepower required (water horsepower) if 50 gallons per minute is pumped?

$$Whp = \frac{gal/min \times lbs/gal \times ft\text{-}lbs/lb}{\frac{ft\text{-}lbs/min}{HP}}$$

= 1.26 horsepower

Since all the power delivered by the driving unit cannot be converted to useful work, the ratio between output and input is called pump efficiency.

Power required to drive the pump, or "brake horsepower" is computed by this formula:

$$bhp = \frac{whp}{\text{pump eff}} = \frac{gpm \times 8.33 \times H}{33{,}000 \times \text{pump eff}} = \frac{gpm \times H}{3960 \times \text{pump eff}}$$

If the efficienty (eff) of the pump is 65%

$\frac{1.26}{0.65}$ = 1.94 horsepower must be delivered to the pump.

Again since motors are not 100% efficient

$$\text{Motor hp} = \frac{whp}{\text{pump eff} \times \text{motor eff}}$$

$$= \frac{gpm \times H}{3960 \times \text{pump eff} \times \text{motor eff}}$$

If the motor efficiency is 80%

$\frac{1.26}{0.65 \times 0.80}$ = 2.425 horsepower must be delivered to the motor in order to pump 50 gpm against a total head of 100 feet.

Flow in Open Channels. Flow in open conduits and in partially filled pipes is affected by the same factors as in pipes flowing full. These factors determine the slope required for an open channel to maintain a certain flow and velocity. The velocity is actually determined by the slope of the water surface, but this is usually also the slope of the bottom of the channel and the water flows at a constant depth. The slope of the water surface is called the hydraulic gradient. The friction between water and the conduit walls depends upon the roughness of the surface, but the formula for it is different because the liquid now has a free surface and the length of contact depends upon the shape of the channel and the depth of flow. These factors are combined in the "hydraulic radius", which is found by dividing the cross-sectional area of the flowing water by the distance around that area along the walls of the channel. This distance is called the "wetted perimeter" of the channel (see Figure 10). Thus,

$$\text{Hyd Rad } r = \frac{A}{W} \text{ feet (figure 10)}$$

From these considerations, there has been developed the Chezy formula:

$$v = C\sqrt{rs} \text{ feet per sec}$$

where C = coefficient based on roughness, slope and value of r

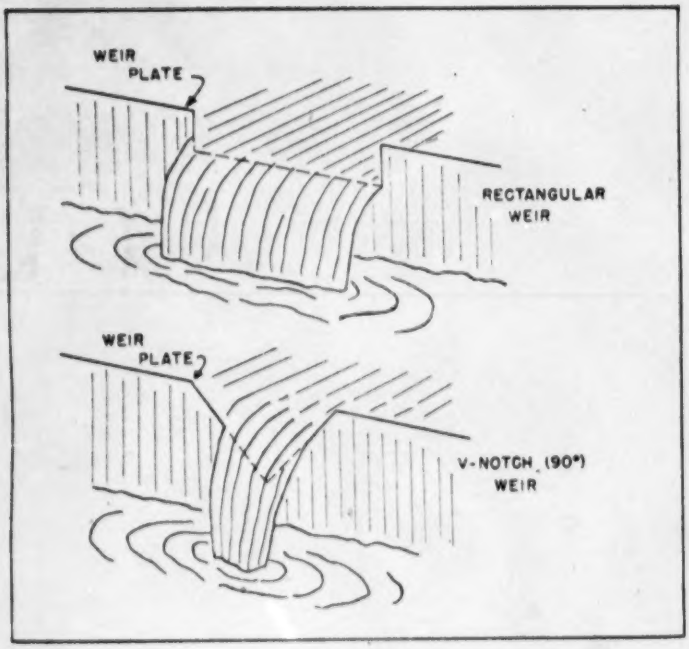
s = slope of the hydraulic gradient or water surface in open channels, usually expressed as ft per foot or ft per thousand feet. Thus, a slope of .004 indicates a drop of four feet in a thousand foot length.

The two principal formulas for determining C, the Kutter and the Manning formulas, depend largely upon values of "n" which is the coefficient of friction. These values have become quite well known for various types of surfaces and materials. Thus n = .013 is commonly used for design of vitrified tile pipes and for large diameter pre-cast concrete pipes.

Tables and diagrams have been published from which velocities, rates of flow and slopes can be determined for various diameters of pipes and values of "n".

Weirs. There are numerous ways of measuring flowing water, but three devices most commonly used are weirs, Venturi meters, and Parshall flumes.

The weir consists of rectangular opening or V notch opening with sharp edges. The weir is set vertically so that the flow passes over it and falls away from it.



WEIRS

Figure 13

It is only necessary to measure the height of water above the crest of the weir at a point sufficiently upstream which avoids the curve of the water surface over the weir. In placing a weir, two points must be considered. First, the weir should be installed in the channel so that the velocity of the water approaching the weir is relatively low. Second, the "head" on the weir is not the depth of water as it passes over the weir proper but is the difference in elevation between the edge of the weir and the water upstream a short distance. In Figure 14, both of these points are illustrated. By using the head measurement the flow is determined from the formula:

Rate of flow $Q = 3.33\ L\ h\sqrt{h}$ cfs (for a suppressed weir)

and

$Q = 3.33\ (L - \frac{h}{5})\ h\sqrt{h}$ cfs (for a contracted weir)

where h = the height of horizontal water surface above crest of weir, L = horizontal length of weir.

The V notch weir is more accurate than the rectangular weir for small flows. For a 90 degree notch, the formula is: (Figure 15)

$Q = Ch^2\sqrt{h}$ cfs where

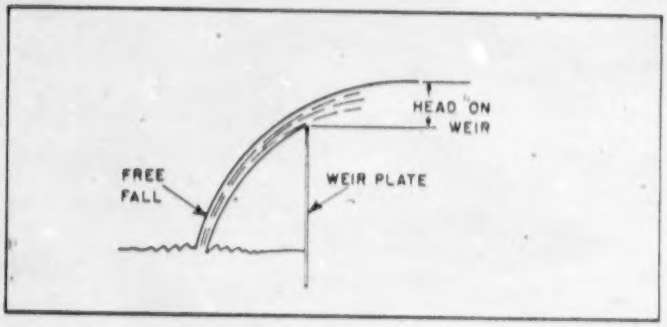
C is a coefficient depending upon the material of the weir and the range of head. Values of C are given in handbooks for various materials and heads. The V notch weir is suitable for

measuring flows from 10 to 3,500 gpm. Another formula which may be used with a V notch weir with 90° angle is

$Q = 2.5\ h^{5/2}$

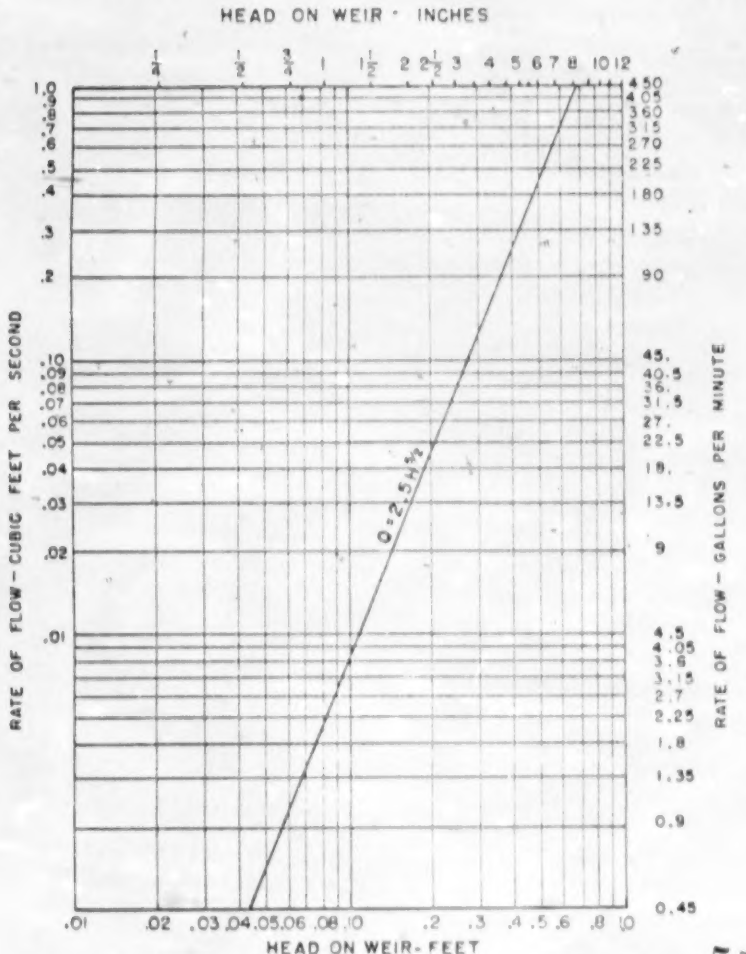
where Q = rate of discharge in cfs
h = "head" on weir in feet (Figure 15)

Using the chart. (Figure 15)
If h is measured to be 0.20 feet then Q = .045 cfs
= 20.25 gpm



HEAD ON WEIR

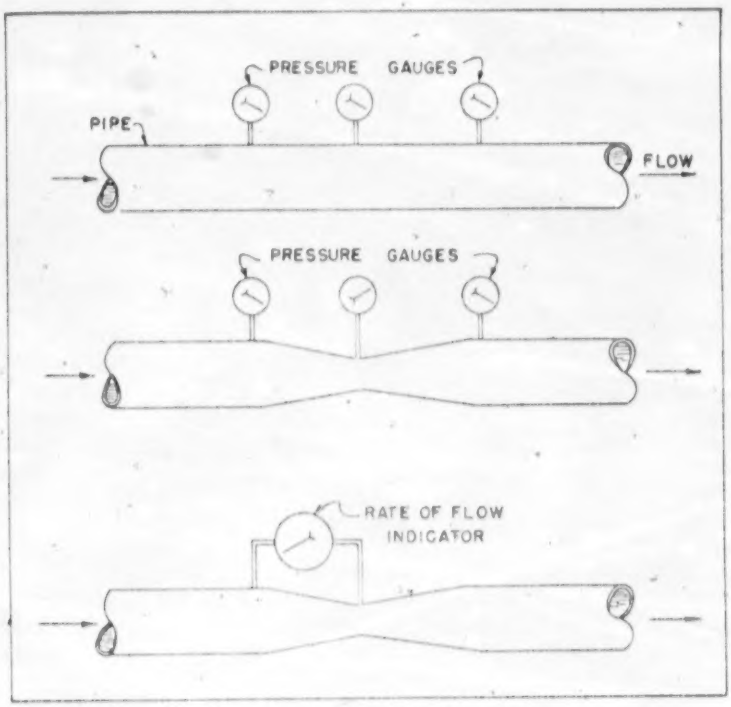
Figure 14



90° V-NOTCH WEIR FORMULA -Q=2.5H5/2

Figure 15

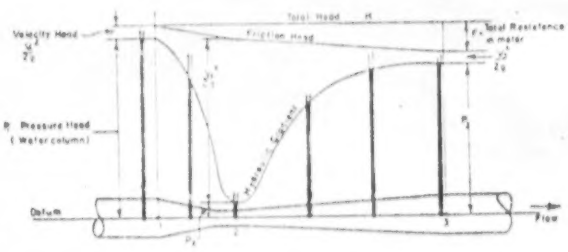
Venturi Meter. This type of flow measuring device is installed in a pipe line and consists of a throat carefully machined to a given inside diameter, a converging section which tapers from the pipe diameter to the throat and a diverging section from the throat to the pipe diameter. (See Figure 16). Taps are provided for measuring pressure head at points just before convergence and at the throat. The only measurement necessary to compute the flow is the difference in pressure head between the two tap points. Figure 17 shows graphically how pressure and velocity heads change in the Venturi Meter.



VENTURI TUBE

Figure 16

FIG. 17

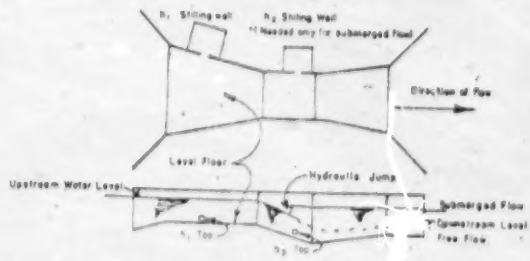


PRINCIPLE OF THE
VENTURI METER

Parshall Flume. This type of flow measuring device was developed for measuring irrigation water in open channels where there may be debris and silt and where little loss of head can be permitted.

In principle, the flume is similar to the Venturi meter. It has an inlet section with sides converging slowly to a throat of fixed dimensions and an outlet section diverging more rapidly to the original channel width. For the usual non-submerged condition only measurement of the depth of water at a fixed distance upstream from the throat is necessary to determine the flow. The flume may be constructed of almost any building material. For greatest accuracy the throat is often made to accurate dimensions from corrosion resistant metal. Figure 18 illustrates the Parshall Flume.

FIG. 18

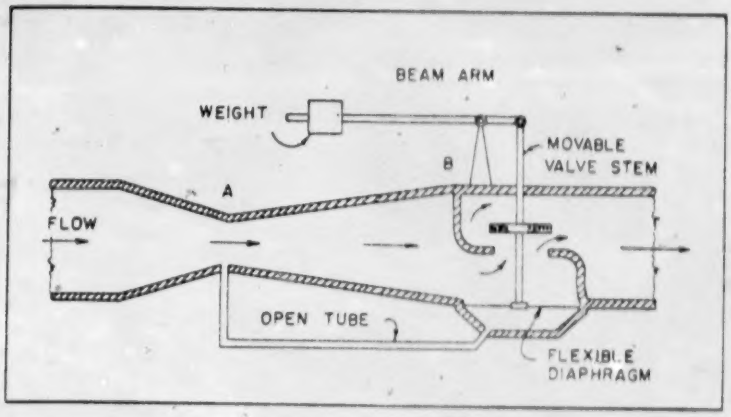


PARSHALL FLUME

Magnetic Flow Meter. Each of the previously described flow measuring devices involves an appreciable loss of head. A new development consists of a non-magnetic tube of the same internal diameter as the pipe line across which a magnetic field is established. Water flowing through the magnetic field produces a voltage proportional to the velocity. This voltage is converted by electrical and mechanical means to indicate and record the rate of flow.

An important operating and maintenance requirement of any flow measuring device is that pressure connecting stilling wells, floats and float tubes must be kept clean.

Rate of Flow Controllers. These are used to maintain flows at constant rates. Generally, all of the newer models depend on the Venturi principle to control a movable diaphragm or a pilot valve. This in turn actuates a main valve so as to control the size of an opening so that the desired amount of water is passed. Figure 19 shows a section through one type of controller. Actually this particular type of controller has two valves on the vertical stem and two valve seats but, for simplification, only one has been shown.



RATE OF FLOW CONTROLLER

Figure 19

The weight is placed at the desired point on the beam arm which corresponds to a certain rate of flow through the valve. At this particular rate of flow the unit pressure at point "A" will be less than the unit pressure at point "B". The unit pressure at point A is transferred, by means of the small open tube, to the compartment below the flexible diaphragm. The downward total pressure on the diaphragm is then greater than the upward total pressure. This results in a tendency for the valve stem to move downward. This tendency is counteracted by the weight at the proper location on the beam arm. At the desired rate of flow everything is in balance.

Pumps. Pumps have many uses in waterworks practice. Though there are many types, practically all water pumps may be classified into two general categories: displacement pumps and velocity pumps.

Displacement pumps employ some mechanical means (plungers, pistons, gears or cams) for forcing specific volumes of water through the units. Velocity pumps impart a high velocity to water and convert the velocity head into pressure head which forces the water through the apparatus.

Either type of pump raises the pressure on inlet side to a higher pressure on the outlet side. The specific means for bringing this about are quite different for the two types. Displacement type pumps, when operating at a particular speed, will take specific unit volumes of water and mechanically force the water out of the pump at a certain rate without regard to conditions beyond the pumping unit. When the resistance to flow beyond the pump is increased, the pressure will be increased. The only limit is the available horsepower and the physical strength of the discharge pipe or the pump. In other words, if something goes wrong on the discharge side of the pump to stop the flow, something may have to "give" and serious damage may result.

This is not the case with a velocity pump. A velocity pump merely causes the water to move with a very high velocity within the pump, usually in a circular direction. Under most conditions the amount of water which passes through the pump depends upon the resistance to flow on the discharge side. If the resistance is too great, for example if a valve is closed, the pump will continue to operate. This will produce the maximum pressure obtainable from that particular pump and speed of operation, but no water will pass through the pump. Probably no damage will result unless the pump is allowed to run until it over-heats.

Displacement pumps may be subdivided into two general types -- reciprocating and rotary. The reciprocating type, equipped with either plungers or pistons, includes direct acting, single or duplex, steam pumps, crank and flywheel pumps, and plunger pumps. Rotary pumps may be either cam, screw or gear types.

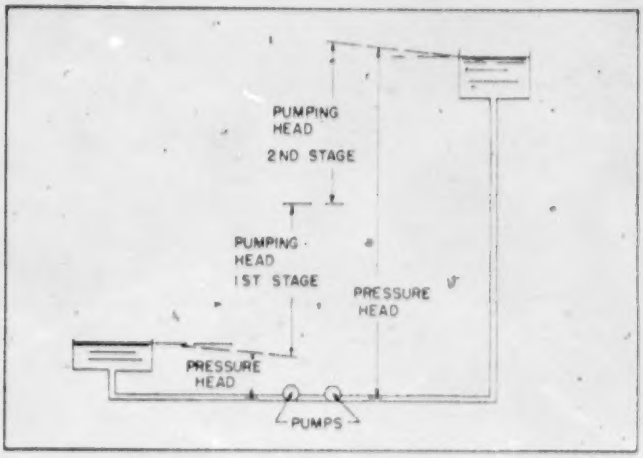
Velocity pumps may be subdivided into several general types including centrifugal, propeller, mixed flow, and turbine units.

Displacement pumps have certain advantages over velocity types. In displacement pumps the quantity of liquid delivered does not vary with the discharge head; they are easily primed; many act like air pumps and prime themselves when the suction head is low. They will operate smoothly on high suction lifts up to 25 feet or so. For high heads and small quantities, the reciprocating pump is probably still the best. For many applications, the velocity pump, particularly the centrifugal pump, has displaced the reciprocating pump. Advantages of velocity pumps are lower initial cost, generally higher efficiency and easier installation and maintenance.

Centrifugal Pumps. In the centrifugal pump, pressure is developed almost entirely by centrifugal force. Water enters at the center of an impeller which is rotated at high speed. Pressure is exerted and water moves to the outside. A specially shaped casing around the impeller discharges the water through a single opening to discharge line. There are various types of impellers. These include the open type which is commonly used

for pumping sewage and the closed type which is commonly used for pumping clear water. The water may enter at one side of the impeller in the side suction pump or on both sides in the double suction pump. Two or more pumps are used in stages when pumping against high heads. More than one stage can be obtained by using several impellers mounted on a single shaft. Also, two individual pumps can be mounted on a single shaft, driven by one motor, when the head conditions are high. The application of a multistage layout is illustrated in Figure 20.

Centrifugal pumps may be operated with suction lifts. With all but minimum lifts, priming arrangements may be required.



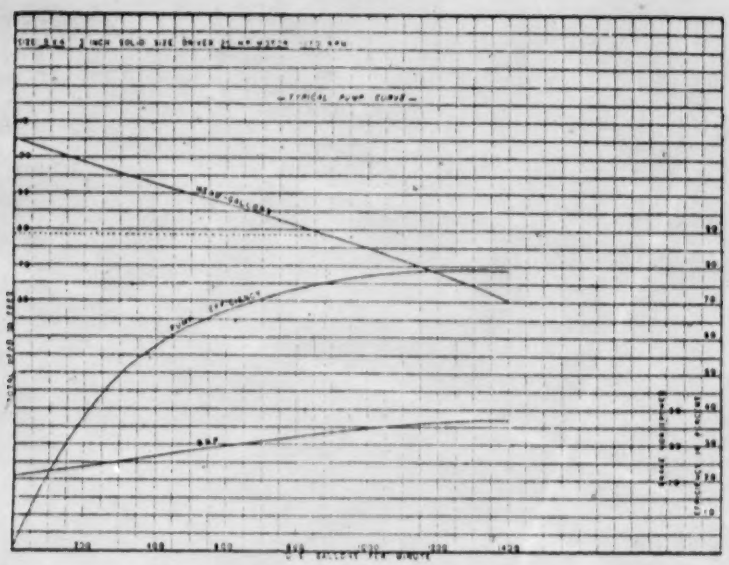
TWO STAGE PUMPING

Figure 20

The performance and operating characteristics are given on a pump curve sheet supplied by the manufacturer for each pump. On Figure 21 the curves show the discharge in gallons per minute (gpm) of the pump at various heads, the pump efficiency under different head-discharge conditions and the brake horsepower under various head-discharge conditions. As the head increases the discharge decreases until the shut-off head is reached.

On the pump curves, Figure 21, dotted lines indicate how values can be read from these curves. The pump for which these curves were prepared, when operated at 1170 revolutions per minute (rpm), will deliver 880 gpm at a total head of 79 feet. The brake horsepower (bhp) of the pump is 23 and the pump efficiency 75%. For a motor with an efficiency of 92 percent, the mhp (motor horsepower) should be 25. (Refer to power requirement for pumping). The shutoff head at which no water is delivered is 105 feet.

FIG. 21



TYPICAL PUMP CURVE

Large centrifugal pumps usually operate at slow speeds to minimize wear and maintenance costs.

The other velocity pumps have, in general, similar operating characteristics. They may very considerably in construction and have different applications to water pumping problems. Propellor types are usually limited to low heads and the turbine type, with several stages, is most often used as a deep well pump.